Agroclimatic Atlas of Andhra Pradesh

V.U.M. Rao, B. Bapuji Rao and B. Venkateswarlu

All India Coordinated Research Project on Agrometeorology
Central Research Institute for Dryland Agriculture
Santoshnagar, HYDERABAD - 500 059

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Phone : 91 - 040 - 24530177, 24530161 (O), 24532262 (R)
Fax : 91 - 040 - 24531802
Web : http://www.crida.in
E-mail : director@crida.in

GIS Maps: Mrs. P. Latha

Secretarial Assistance: Miss. N. Pallavi

Cover Page: Mr. A. Mallesh Yadav

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V.U.M. Rao, B. Bapuji Rao and B. Venkateswarlu

Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad - 500 059

डॉ. अलोक कुमार सिक्का
उप महानिदेशक (प्रा.सं.प्र)

Dr. Alok K. Sikka
Deputy Director General (NRM)

भारतीय कृषि अनुसंधान परिषद
कृषि अनुसंधान भवन-II पूसा, नई दिल्ली 110 012

INDIAN COUNCIL OF AGRICULTURAL RESEARCH
KRISHI ANUSANDHAN BHAWAN-II, PUSA, NEW DELHI - 110 012

Ph. : 91-11-25848364 (O), 24121571 (R)
Fax : 91-11-25848366
E-mail : aksikka@icar.org.in; aloksikka@yahoo.co.in

Preface

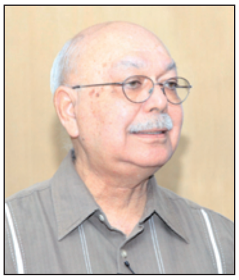
Climate is the paramount factor determining the sustainability of agricultural systems. Properties of climate derived from long-term observations employing appropriate statistical tools ensure that the usual range of variation in the climatic parameters is known. Notwithstanding the difficulties in short-term accurate weather forecast, a proper understanding on the climate prevailing over a region is essential to improve the productivity of agricultural systems. The benefits of understanding the weather aberrations help in the establishment of techniques and controls that foster a healthier agricultural planning.

Growing concern for food security and dearth of proper understanding on the impacts of impending global warming on cropping patterns and agricultural output are posing great challenges to agricultural scientists and policy planners charged with managing the risks associated with farming. Changes in technology, climate variability and new options for value-added crops mean producers require more detailed climate, soils and moisture information. To develop new genetic strains and evolving the most effective agricultural practices, detailed climatic information is required, especially on rainfall, atmospheric temperature, humidity and other parameters. In view of this, agroclimatic atlas of Andhra Pradesh state has been prepared. The purpose of this atlas is to present climatic information of importance to agriculture in the state and to make that information easily available to all stakeholders including agricultural producers, entrepreneurs and researchers.

Authors of this atlas have made a painstaking analytic work at the micro-level and I believe that besides catering to the needs of the farmers and agricultural scientists of Andhra Pradesh, this atlas will serve as a reference material to different stakeholders both at the state and national level. I extend my heartiest congratulations to the authors for their untiring efforts in preparing a very comprehensive, relevant and useful document.

25th October, 2013

(Alok K. Sikka)



S. M. Virmani, Ph.D.
Former Principal Agroclimatologist (ICRISAT)
811A, Road 41, Jubilee Hills,
Hyderabad - 500 033.

Foreword

Climate and weather have directly a pervasive effect on land use, crop quality and its productivity. Climate thus impacts all aspects of our environment and life. Further, climatic variability and climate changes and the occurrence / frequency of extreme weather events are important for the stability of agricultural production and its quality. The thermal and hygric environments are considered as the two main weather variables that determine crop yield, particularly in the rainfed agriculture. To understand the influence of these weather elements, in terms a study of their physical and biological impacts is essential for sustaining our agriculture. In the absence of quantitative climatic data, land use planning, forecasting of weather and climate related research and services by agrometeorologists cannot proceed to suitably assist the farming communities to sustain crop production. Meteorological data are also an essential to supplement the assessment of impacts of land-use sector on the environment and changes in climate. Meteorological observations are therefore needed, at different spatial scales, both for advance planning of farm activities and for real-time interventions in the process of crop production.

The state of Andhra Pradesh contributes about 20 million tons of food (about 8%) to the country's annual grain production. Its 970 km long coast line on the east frequently exposes the state to cyclones and monsoon depressions in the Bay of Bengal. On the southern side of the state, lies a vast rain shadow area. Under such differential climatic conditions, number of eco-climates occur in the state and a variety of crops are grown. Some 55% of the net cultivated area of the state is rainfed. These areas oscillate under different rainfed crops year-to-year in accord with the performance of monsoons. Thus, the productivity of rainfed crops is largely dependent on both the temporal and spatial distribution of rain. Therefore, in order to introduce conservation sustainable agricultural practices, a complete understanding of the length of the growing season and its inter-and intra-seasonal variability together with the incidences of droughts, floods and their probabilities at the micro and meso-scales are urgently needed. These require an input of long-term climatic data from a high density network of meteorological observatories. I understand, that the India Meteorological Department (IMD) collects, assembles and records met-data from some 300 locations in the state. Due to the extreme diversity of agroecologies found in the state the number of meteorological observatories or locations and the available data are not sufficient for micro level planning of agricultural operations. Currently the data are available for a sufficient length of time for analysis at micro (mandal) level for rainfall only. The authors of this monograph have collected carefully, analysed and estimated other parameters of climate (which are available at the district level) and have used appropriate geo-spatial tools to enlarge the observed data to the mandal level. This is truly a painstaking analytic research work; I therefore have no hesitation in complimenting the authors for their efforts in assembling a voluminous meteorological database, putting it in order and analyzing it in such a way so as to serve as a guide for planning activities of various agriculture related sectors.

The work contained in this volume, though of a first approximation nature, is excellent and an unique attempt of agro-climatic analysis at micro and meso levels. I believe, a very useful information has been generated through these studies. It would serve as a pace setter and an example for future climate research. When replicated for other areas, such research can be of great value and assistance in broadening base-line natural resource management work for the introduction of sustaining conservative agriculture production systems.

22nd October, 2013

(S.M. Virmani)

Acknowledgements

Agricultural production in the state of Andhra Pradesh is at the mercy of monsoonal rains during the *kharif* season and cyclones / depressions that visit at harvest very frequently. Climatic information at the micro-level is very much needed in crop planning as well as for day-to-day field operations. Lack of such information for the state has compelled us to source enormous data from various Organizations / Institutions / Departments and Research stations of ANGRAU. We tried to extract information and presented in a simple and practically usable form. We thank Dr. A.K. Sikka, DDG (NRM), ICAR, New Delhi for his keen interest, support and guidance at all stages of the study.

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AUTHORS

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Executive Summary

Crop production globally is majorly governed by weather and climate. Challenges to sustain the current production levels are on a rise due to increased climatic variability, occurrence of extreme events because of impending climate changes. For proper planning of the agricultural production systems in a region, therefore a detailed analysis of climatic data/ information is a pre-requisite. For farm level decisions, for risk management, weather information at micro level is needed. Climatic information at micro (*mandal*) level for the state of Andhra Pradesh has not been available hitherto. This study attempts to present an Agroclimatic Atlas for the state of Andhra Pradesh covering all aspects of agrometeorology. It is a first approximation - a model study. It presents an in-depth analyses. As a special feature, it attempts to present a detailed agroclimatic analysis of Anantapur district. The aim of this study is to demonstrate how agroclimatological analysis could form a basis for formulating efficient management of natural resources in the crop planning.

Agricultural scenario of Andhra Pradesh

Amongst cereals, paddy, maize and sorghum are the principal cereal crops of the state. The area under paddy is about 35 lakh ha with a production of 136 lakh tonnes and productivity of 3090 kg ha^{-1}. Maize is the second largest crop with an area of about 8 lakh ha, production of 38 lakh tonnes and a productivity of 4000 kg ha^{-1}. Sorghum which occupied an area of 25 lakh ha in the 1970s, is now grown on about 3 lakh ha. The major grain-legume crops of the state are chickpea, pigeonpea, blackgram and greengram. Productivity of chickpea is around 1200 kg ha^{-1}. Pigeonpea area is about 4.53 lakh ha with a productivity of only about 360 kg ha^{-1}. Inter-annual variability in yields is largely weather driven.

Area, production and productivity of blackgram has varied over the years. Area under green gram has showed a marginal decline in the recent years but production has enhanced due to an improvement in its productivity. Both of these pulses crops are facing threat from better remunerative crops and of the wide scale occurrence of yellow mosaic virus.

Groundnut is the principal oilseed crop grown on 16.5 lakh ha. The production and productivity vary considerably over years due to variations in the amount of distribution of rainfall. Anantapur district grows about 8 lakh ha of the crop; and is the largest groundnut growing district in India.

Sunflower is the second largest oilseed crop grown in the state. There is a large inter-annual variability recorded in the production of castor. Its area and production have consistently declined over the years. Castor is highly sensitive to excess moisture during its flowering and pod development stages. The receipt of pre-monsoon showers regulates area under the castor each year. Similarly, area under sesame is also recording a sharp decline but production has marginally decreased.

Cotton is the principal commercial crop of the state and is cultivated in more than 13 lakh ha. In years of early dry spells during rainy season, more area is devoted to cotton owing to its relatively higher drought tolerance. Chillies is another important commercial crop grown in over 2 lakh ha, but production and productivity of this crop has steeply increased in recent years. A gradual increase in sugarcane production has been noted which is due to an increase in the area under the crop. However, inter-annual variation in the productivity of sugarcane is primarily related to the weather, since large area under the crop is rainfed.

Climate in general

About 63% of the geographical area of Andhra Pradesh is semi-arid, 18% is dry sub-humid (mainly in north coastal districts) and about 15% of the area in *Rayalaseema* is arid. Majority of the *mandals* in coastal districts of Guntur, Krishna and Srikakulam are semi-arid. The entire Anantapur district, *mandals* on the western parts of YSR Kadapa, Kurnool, majority of *mandals* in Mahabubnagar and Nalgonda districts and Peddaraveedu *mandal* of the Prakasam district are classified as arid.

a) Rainfall

Annual normal rainfall of the state is 906 mm, out of which Southwest monsoon (June to September) accounts for 67% and Northeast monsoon (October to December) accounts for 24%. The rest (9% of the rainfall) is received during the winter and summer months. There is a large spatial variability in the distribution of rainfall over the regions of the state. Southwest Monsoon (SWM) is predominant in the *Telangana* region (716mm) followed by the Coastal Andhra (620 mm) and the *Rayalaseema* (407 mm), whereas the Northeast Monsoon (NEM) provides maximum amount of rainfall in the Coastal Andhra area (324 mm) followed by *Rayalaseema* (238 mm) and *Telangana* (129 mm). There is a large difference in annual rainfall received across the districts with East Godavari topping the list (1125 mm), the lowest rainfall is observed in Anantapur district (546 mm). The variability in the rainfall during SWM was found to be highest in Anantapur district (36%) followed by SPSR Nellore (35%) and the least in Vizianagaram (17%). Highest variability in NEM rainfall was observed in Nizamabad (95%) followed by Adilabad (94%) whereas it is relatively stable in SPSR Nellore (33%).

The total annual rainfall is received in 39 to 58 rainy days with a variability of 15%. On an annual basis, the average number of rainy days in coastal Andhra region are 52 followed by 46 in *Telangana* and 39 in *Rayalaseema* regions. Highest number of rainy days are observed in Visakhapatnam and Vizianagaram districts (58 days).

During the SWM season, the state receives 608 ± 177 mm. Adilabad district of *Telangana* receives highest amount of annual rainfall (904 mm). In the coastal region, West Godavari and Srikakulam districts receive high amount of rainfall (725 mm). Lowest rainfall is noted in Anantapur district (322 mm) followed by SPSR Nellore (328 mm). Variability in rainfall over the entire state is high (29%) compared to the national average (11%) or that of southern peninsular region (15%). Lowest variability is seen over Coastal Andhra (26%) and highest in *Rayalaseema* (32%) and it is intermediate over *Telangana* (28%). At the district level, highest variability of rainfall is observed in the Anantapur district (36%) and lowest in Vizianagaram (17%). SWM rainfall in the state is spread on an average over 33 days. Highest number of rainy days are observed in the *Telangana* region (37 days) and lowest over the Ralayaseema region (22 days); and the number of rainy days are intermediate over the Coastal Andhra region (33 days). Khammam and Adilabad districts record maximum number of rainy days (42 days) while, these were least in Anantapur (18 days).

Rainfall during the NEM season for the entire state is 214 ± 129 mm with a variability of 60%. Coastal Andhra receives significant amount of rainfall (304 mm) and *Rayalaseema* receives a fairly good amount of rainfall (232 mm) while, the lowest NEM rainfall is recorded in the *Telangana* region (116 mm). SPSR Nellore district receives abundant rainfall (656 mm) during this season; it is lowest in Adilabad (93 mm).

Trends in time series

Around 85 percent of the *mandals* in the state showed no significant trend in annual rainfall. However, majority of the *mandals* in Medak district showed declining trend in annual rainfall followed by Karimnagar, Mahabubnagar and Nalgonda districts. On the other hand, increasing trend in annual rainfall is observed in many *mandals* of Anantapur, Kurnool, Prakasam and also in few *mandals* of SPSR Nellore, Krishna and Vizianagaram districts. There is no significant increasing / decreasing trend observed in 80 per cent of *mandals*. Most of the *mandals* of the drought-prone districts of *Rayalaseema* region (Anantapur, Chittoor, YSR Kadapa and Kurnool) showed an increasing trend. At the same time, a declining trend is noticed in several *mandals* of *Telangana* region, Prakasam, Guntur and West Godavari districts.

In 17 out of 45 *mandals* of Medak district, a declining trend was observed in SWM rainfall. In Medak 10% of the geographical area showed a strong decreasing rainfall tendency. At the same time, increasing trend in summer monsoon rainfall is observed in large number of *mandals* of Khammam and Visakhapatnam followed by Kurnool and Krishna districts. The trend of number of rainy days during the summer monsoon season showed same pattern as in the case of amount of rainfall. However, a declining trend is evident in about 20 *mandals* of Nalgonda district.

Generally, no significant trend of changes in the amount of rain events has been observed in most parts of the state under both categories (75-100 mm and >100 mm day^{-1}). However, significant increasing trend in 75-100 mm category has been noted in many *mandals* of Krishna, West Godavari, Guntur, SPSR Nellore and Vizianagaram districts. A declining trend is observed in Karimnagar and Medak districts in the 75-100 mm category. In the *Rayalaseema* region, a decreasing trend is also observed in *mandals* like Chintha Kommadinne, S. Mydukur, Yerraguntla, Kadiri, Tadimmarri and Uravakonda only while Rayachoti *mandal* of YSR Kadapa district showed an increasing tendency. For rainfall >100 mm per day category, only 32 *mandals* in the state showed an increasing trend. At the same time, declining trend has been observed in 20 *mandals*.

Rainfall during SWM season significant increasing and declining trends in 75-100 mm day^{-1} category is observed in 33 and 27 *mandals*, respectively. Maximum number of *mandals* showing significant increasing trend is seen in Guntur (6 *mandals*). Declining trend is observed in *Telangana* region particularly in Karimnagar and Adilabad districts. A few *mandals* of Khammam, Warangal and Adilabad districts in the *Telangana* region and West Godavari and Visakhapatnam districts in the coastal region showed significant increasing trend whereas declining trend in some *mandals* of SPSR Nellore, YSR Kadapa, Anantapur, Chittoor and Vizianagaram districts in the >100 mm rainfall category were observed.

No significant increasing or decreasing trend is observed in maximum one-day rainfall in majority of *mandals* (220 out of 280 *mandals*). Increasing and decreasing trends are noted in 30 *mandals* each. High daily rainfall episodes showed an increasing trend mainly over the Coastal Andhra region followed by the *Telangana* region while a declining trend is noted over the *Rayalaseema* region.

A significant increasing trend in maximum 5-day cumulative rainfall has been noted in eight *mandals* and a declining trend is observed only in two *mandals*.

Out of 280 *mandals* analyzed, only 16 showed increasing tendency in mean daily rainfall intensity. On the other hand only two *mandals viz.*, Piduguralla (Guntur) and Gajapathinagaram (Vizianagaram) *mandals* showed a declining trend.

No significant increasing or declining trend has been noted in 93 per cent (260 out of 280) *mandals* analyzed with respect to length of dry spell. An increasing trend has been evident in six *mandals*, out of which three are located in East Godavari district. A declining trend is observed in the length of dry spell in 14 *mandals* out of which 10 *mandals* are located in the *Rayalaseema* region.

There is no significant increasing or decreasing trend observed in the length of continuous wet spells in 90 per cent (250 out of 280) *mandals* in the state. The length of wet spells showed an increasing trend in 22 *mandals* out of which 13 *mandals* are located in the Coastal Andhra region and 9 *mandals* are situated in the Rayalaseeema region. A declining trend is observed only in 8 *mandals*.

In majority of the districts, except Anantapur and SPSR Nellore, the rainy season commences in the 24th SMW and ends by 40th SMW. In Chittoor, SPSR Nellore and Prakasam districts, the rainy season is limited to 38 to 49 SMW. Isolated rainfall events are noted over the entire state during 50 to 20 SMW and the rains get momentum with the onset of monsoon from 21 SMW onwards.

About 445 *mandals* in the state which are majorly spread in Coastal Andhra region, Chittoor district of *Rayalaseema* region and all districts of the *Telangana* region (except Nalgonda and Mahabubnagar) receive annual rainfall in the range of 600-800 mm. An expected annual rainfall in the range from 400 - 600 mm is observed majorly in the interior region of the state. Lowest amount of annual rainfall expected (at 75 per cent probability) occurs in Anantapur district, and also in some pockets of YSR Kadapa, Mahabubnagar and Nalgonda districts.

Majority of the area in the state is exposed to 16 and 24 per cent probability of the occurrence of moderate drought. Moderate drought with probability of 8 to 16 per cent occurs in Srikakulam, Vizianagaram, Visakhapatnam, Khammam, Warangal and Medak districts. Lowest probability of occurrence of drought has been observed in Bobilli *mandal* of Vizianagaram district and the highest probability has been observed in Chigurumamidi *mandal* of Karimnagar district (48%).

Around 80 per cent of the *mandals* in the state show a probability of <2 per cent of occurrence of severe droughts. Probability of 2 to 6 per cent for the occurrence of severe drought has been noted in many *mandals* of Anantapur and Nalgonda districts. Highest probability of severe drought is seen in Y. Ramavaram (29%), Pamarru (18%) *mandals* of East Godavari and Vemanapalli (15%) *mandal* of Adilabad.

Probability for near normal rainfall condition during SWM is above 50 per cent for all 280 *mandals* studied. Probability of 70% and above for near normal conditions has been noted in only one third of *mandals* of Andhra Pradesh (99 out of 280). In the case of moderately dry category, highest probability of 20% and above of rainfall is noted in seven *mandals*. Probability for severely and extremely dry condition to occur has been observed in 42 and 113 *mandals*, respectively. However, probability of occurrence of severely dry conditions is highest (13%) in Kambadur and Kuderu *mandals* of Anantapur district and the probability of extremely dry condition is highest (8%) in Adoni *mandal* in Kurnool district.

Probability of the occurrence of near normal conditions is above 50% during the northeast monsoon season in all the 280 *mandals* studied. *Mandals* in SPSR Nellore district which receive around 60 per cent of annual rainfall during this season, have a probability ranging from 56 per cent (Venkatagiri *mandal*) to 71 per cent (Atmakur *mandal*) of recording normal rainfall.

Length of Growing Period (LGP)

The LGP occurs between 120-150 days in the districts of Adilabad, Nizamabad, Karimnagar, Medak, Warangal, Ranga Reddy, Khammam, Nalgonda, Mahabubnagar, Kurnool and Prakasam. LGP of >180 days is observed in Srikakulam, Vizianagram, Visakhapatnam and parts of East and West Godavari, Chittoor and SPSR Nellore districts. It is in the range of 150 to 180 days in Krishna, Guntur, parts of Chittoor, SPSR Nellore, Khammam, East and West Godavari districts. The LGP ranges between 90-120 days in parts of YSR Kadapa and Anantapur districts. However, in majority of the *mandals* of Anantapur district, the LGP is < 90 days.

In 8 out of 22 districts of the state, the growing season commences generally during 25th SMW and in the remaining districts, the growing season commences during 26th to 29th SMW. A delayed commencement by 30th SMW is noted in SPSR Nellore, Prakasam and Anantapur districts.

Growing season terminates early in most of the *Telangana* districts (in 43 to 44 SMW) compared to coastal districts (in 46 to 48 SMW). Crop growing season extends by two weeks on an average with a corresponding increase in water holding capacity of the soil by 50 mm. On an average, the length of growing season is longest in coastal districts of the state (22 weeks), followed by *Rayalaseema* (19 weeks) and the districts in *Telangana* (18 weeks) where soils have a water holding capacity of 50 mm. The figures for soils having 100 mm water holding capacity are 25, 21, 20, respectively. For soils having 150 mm water holding capacity the average duration for coastal, *Rayalaseema* and *Telangana* districts are 27, 22 and 22 weeks, respectively. In soils having 200 mm water holding capacity, the length of growing season on the average are 30, 23 and 24 weeks in Coastal, *Rayalaseema* and *Telangana* districts, respectively.

b) Other climatic elements

Mean annual temperature of the state is 33.2°C. A peak in temperature occurs during summer season (37.4°C) and the lowest temperature occurs during the NEM season (30.5°C). Average temperatures are ± 33.1°C during SWM season. Coastal Andhra region experiences relatively low temperatures during winter and summer seasons but higher temperatures during SWM and NEM seasons compared to the two other regions of the state. Highest temperatures (34.5 to 35.5°C) are observed in the northern parts of Adilabad and eastern parts of the Kurnool district.

The state as a whole experiences a minimum temperature of 22.4°C on an annual basis. However, there are regional differences. The coastal region experiences higher temperatures (23.9°C) compared to the *Telangana* region (21.4°C). East Godavari district records highest annual minimum temperatures of 24.9°C whereas Medak (20.0°C) district experiences relatively cooler temperatures.

On a monthly basis, state as a whole experiences high morning humidity during October (84%) and least humidity is recorded during May (66%).

The mean annual wind speed for the entire state is 6.7 kmph with *Telangana* region recording highest average wind speed of 7 kmph. Coastal region is relatively calm with an average wind speed of 6.3 kmph. June is the month with high wind conditions for the entire state (10.2 kmph).

Mean annual number of hours of bright sunshine for the state are 7 hrs/day with *Telangana* (7.3 hrs/day) receiving sunlight for a longer period. Anantapur (8.1 hrs/day) is the brightest district and Srikakulam (5.7 hrs/day) is the dimmest. February month is the month with longest days (9 hrs/day) and July is the month of days with a shorter day length (4.4 hrs/day). Srikakulam district receives sunlight for the shortest period of 2.8 hrs/day in the month of July.

Average total annual evaporation in the state is 1945 mm. Evaporation in the *Rayalaseema* region is the highest (2357 mm) and it is lowest over Coastal region (1634 mm). Amongst the districts, Anantapur ranks first with an annual evaporation of 2674 mm and least evaporation is recorded in Warangal (1255 mm). May is the month with maximal evaporation. The mean total evaporation for the month of May is 251 mm for the entire state with highest recorded in Medak (363 mm) and the least evaporation occurs during May is observed in Warangal (146 mm) district.

c) Agrometeorological production constraints and opportunities

Identification of areas prone to delayed monsoon thus suitable for the promotion of short duration paddy cultivars to tackle planting of over-aged seedlings in tankfed areas. Use of hydrological models coupled with seasonal rainfall forecast of monsoon has been observed to help in giving advance information on the schedule of water release. By using basin models, the areas likely to be inundated can also be identified. Mapping of the areas prone to frequent floods with the help of historic rain data aids in the design, development and maintenance of appropriate drainage systems in the agricultural regions.

In the cotton growing tracts of Andhra Pradesh, advance information with respect to the late arrival of monsoons could help in the selection of cultivars / cropping systems and rescheduling of fertilizer dosages / application and the adoption of soil conservation measures. Information on possible break in monsoons would also help in assessing the likely buildup of abiotic stresses in cotton. High incidence of boll worm (or *spodoptera*) is likely under such situations and agromet advisories could help in the taking up prophylactic measures. Any information on the impending early monsoon withdrawal could potentially help the farmers in rescheduling the fertilizer applications or resorting to foliar nutrient sprays. During high rainfall episodes, and prolonged wet spells are expected, cotton crop is sensitive to high humidity when boll rot occurs; therefore prophylactic measures could be taken up if timely and precise agromet advisory system has been developed and in place.

Information on the high probability of break in monsoon conditions in grain legumes growing areas can assist in developing agromet advisories on intercultural operations, thinning out and vigorous adoption of soil moisture conservation practices. In case of prolonged delay in the onset of southwest monsoons, farmers resort to sowing of pulses on the receipt of rains, late in the season. In such situations, advisories on the likely incidence of biotic stress are crucial. For example, sowing of chickpea in the month of September exposes the crop to *sclerotium* collar rot.

Seasonal agromet advisories are of great assistance in the process of selection of appropriate cultivars of groundnut and other oilseed crops. If onset of monsoon is delayed or sufficient rains have not been received till July, alternate crops to groundnut can be suggested, hence seasonal weather forecasts are vital to minimize the losses at farm level. Break monsoon conditions create nutrient deficiency in oilseeds and early information on mid-season dry spell could certainly assist the adoption of timely corrective measures before nutrient deficiencies occur.

In the case of sugarcane, its yields are affected by both the deficit or excess of moisture and lack of rainfall during July and August results in a substantial reduction in cane yield. Application of trash mulching @ 3 t ha^{-1} during dry spells improves the cane yields. Like-wise, the crop when subjected to water logging affects the sucrose content. It is reduced, thus decreasing the recovery of sugar. High winds lodge the crop which depresses juice sucrose and cane weight decreases as well. All these field problems can be addressed by proper and timely availability of agromet advisories.

During break monsoon situations a complex of sucking pest increasingly attack chillies and the crop undergoes nutrient and moisture stress. Issue of agromet advisories well in advance, would facilitate farmers to adopt intercultural operations to conserve soil moisture, and take-up foliar application of nutrients to correct any deficiency. If the onset of monsoon rains are considerably delayed, then advisories on the methods of sowing and appropriate selection of cultivars to be planted can help to sustain the yield at acceptable levels.

Agroclimate of Anantapur - An intensive analysis

A detailed in-depth analysis of the Anantapur district was carried out to its agroclimatic features for an efficient management of its natural resource endowments. Average annual rainfall of Anantapur is 546 mm with a CV of 24% and PET is 2140 mm. Thus, with an aridity index of -73.6, the district is classified as arid. Normal rainfall during SWM and NEM seasons are 338 mm and 156 mm, respectively. The LGP ranges between 91 to 161 days with eight *mandals* having LGP in the range of 91 to 121 days. Twelve *mandals* show an increasing trend in annual rainfall. Out of 41 years, the rainfall during SWM season was near normal in 13, deficit in 16 and was in excess in 11 years. During SWM season, a rainfall on 323 mm normally occurs in 18 days with a coefficient of variability of 24%, and during NEM season there are nine rainy events, on average, with a variability of 35%. Normally each rainfall event during SWM season produces 18 mm rainfall, which is insufficient to bring the top 45 cm of soil to field capacity. The variability in annual rainfall in the recent decade (2001-2010) compared to the previous decade (1991-2000) showed an increase in the north western parts of the district. Differences in variability of June, July and September rainfall were observed in various *mandals* in the recent decades. In Uravakonda *mandal* a decreasing trend in heavy rainfall events (75-100 mm category) has been noticed. Out of 63 *mandals*, the probability of occurrence of mild droughts is very low (-10%) in 10 *mandals*. Probability of getting 2 to 3 drought years in a decade has been recorded in 25 *mandals*. In six *mandals* the probability of occurrence of severe drought is low (10%).

The key to realizing stable yields of groundnut in Anantapur is the distribution of rainfall rather than its total amount. The peg penetration and pod development stages are highly sensitive to dry spells and hence distribution of rains becomes important. The effect of the length of dry spells at different growth stages on groundnut pod yield at Anantapur has indicated that yields decline if the moisture deficit exceeds for three weeks or more in the early vegetative stage of the crop (0-35DAS). The impact of drought is more pronounced during the start of pegging and seed development (51-85 DAS) stages. Pod yields decline drastically in years when the length of dry spell exceeded 30 days at this stage. Frequent failure of monsoon rains during these critical periods is the main cause of the failure of groundnut crop in the district. An amount of total rain of 350 mm during its growing season appears to be critical for obtaining minimal yield of 350 kg ha^{1}. When the seasonal rain is above the 350 mm threshold, the probability of realizing an yield upto 1 ton ha^{-1} or more is ensured in 50% of the year. It appears that during some years, despite high seasonal rainfall, lower yields were realized which signifies improper distribution of rainfall. Of late, the August rainfall in the district has become somewhat uncertain. Cultivars which can tolerate prolonged stress during its re-productive stage need to be bred urgently. In Anantapur district, either Spanish bunch or Virginia bunch types of groundnuts are largely cultivated. These have a duration of 110-135 days. The currently cultivated groundnuts cultivars in vague, can withstand 4 weeks of continuous dry spell.

Research must be undertaken for the development of genotypes that can withstand prolonged dry spells without foregoing pod yield and biomass as both are economically important. Development of early maturing (90 days) drought-tolerant groundnut cultivars and also those suitable for late-sown conditions for areas receiving delayed monsoon may be targeted. Suitability and economic viability of groundnut-millet; groundnut-pulses; groundnut-castor and similar cropping systems need to worked out. Research on development of groundnut-based integrated farming system models with small ruminants is also needed to bring stability, income and livelihood resilience to small holders/ marginal/ SC/ST farmers. There is lot of scope for the promotion of cultivation of short duration chickpeas in the vertisol (black soils) areas. The latest cultivar ‘JAKI 9218’ which is very popular and high yielding may be promoted in the district.

The groundnut (intercropped with pigeonpea and caster) -chickpea cropping system. It is ideal for the district although the district receives a mean annual rainfall of about 566 mm, and on an average it has 5 run-off events per annum. Under such a situation, there is a need for harvesting the rainwater and its judicious use during critical crop growth phases. Farm pond technology has been developed and successfully demonstrated in Anantapur district by several agencies. This technology has been shown to benefit the farmers to provide supplemental irrigation to the crops at critical growth stages when drought occurs. Improvements should also be made in on-farm water management techniques to reduce ground water draft by pumping. This can be achieved by improved irrigation application methods. Adoption of drip and micro sprinkler irrigation systems is important. In case of the availability of excess surface runoff in localized depressions in the agricultural areas, sub surface recharge structures such as recharge shafts or recharge cavities can be adopted for better ground water recharge. About 10-15 blocks in the district are also suitable for the cultivation of clusterbean for gum production. Trials carried out by the Arid-legumes project in the past have shown that 600-800 kg ha^{-1} yield can be obtained under rainfed conditions.

However, due to the lack of market support infrastructure this initiative could not go forward. Now, a time bound action plan needs to be chalked out for promoting clusterbean cultivation for gum production. In recent years, castor has been cultivated in some *mandals*. The performance of the crop during *rabi*-summer is very good and it has paid good dividends. In 15-20 blocks, promotion of castor (varieties in *kharif* and hybrids in *rabi*) can give higher returns than groundnut either as sole or as an intercrop with cluster beans. The area under chickpea is also on the rise especially in *mandals* with (vertisols) black cotton soils. The possibilities for the promotion of high value medicinal and aromatic plants like Aloe vera, lemon grass, and such other crops along with suitable marketing support may be explored. Similarly, introduction of selected horti-pastural systems and horti-agri systems must be explored depending on agro ecological condition.

AGROCLIMATIC ATLAS OF ANDHRA PRADESH

V.U.M. Rao, B. Bapuji Rao and B. Venkateswarlu

भाकृअनुप
ICAR

Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad - 500 059

डॉ. अलोक कुमार सिक्का
उप महानिदेशक (प्रा.सं.प्र)

Dr. Alok K. Sikka
Deputy Director General (NRM)

भारतीय कृषि अनुसंधान परिषद
कृषि अनुसंधान भवन-II पूसा, नई दिल्ली 110 012

INDIAN COUNCIL OF AGRICULTURAL RESEARCH
KRISHI ANUSANDHAN BHAWAN-II, PUSA, NEW DELHI - 110 012

Ph. : 91-11-25848364 (O), 24121571 (R)
Fax : 91-11-25848366
E-mail : aksikka@icar.org.in; aloksikka@yahoo.co.in

Preface

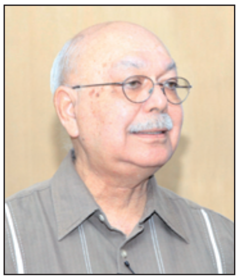
Climate is the paramount factor determining the sustainability of agricultural systems. Properties of climate derived from long-term observations employing appropriate statistical tools ensure that the usual range of variation in the climatic parameters is known. Notwithstanding the difficulties in short-term accurate weather forecast, a proper understanding on the climate prevailing over a region is essential to improve the productivity of agricultural systems. The benefits of understanding the weather aberrations help in the establishment of techniques and controls that foster a healthier agricultural planning.

Growing concern for food security and dearth of proper understanding on the impacts of impending global warming on cropping patterns and agricultural output are posing great challenges to agricultural scientists and policy planners charged with managing the risks associated with farming. Changes in technology, climate variability and new options for value-added crops mean producers require more detailed climate, soils and moisture information. To develop new genetic strains and evolving the most effective agricultural practices, detailed climatic information is required, especially on rainfall, atmospheric temperature, humidity and other parameters. In view of this, agroclimatic atlas of Andhra Pradesh state has been prepared. The purpose of this atlas is to present climatic information of importance to agriculture in the state and to make that information easily available to all stakeholders including agricultural producers, entrepreneurs and researchers.

Authors of this atlas have made a painstaking analytic work at the micro-level and I believe that besides catering to the needs of the farmers and agricultural scientists of Andhra Pradesh, this atlas will serve as a reference material to different stakeholders both at the state and national level. I extend my heartiest congratulations to the authors for their untiring efforts in preparing a very comprehensive, relevant and useful document.

25th October, 2013

(Alok K. Sikka)



S. M. Virmani, Ph.D.
Former Principal Agroclimatologist (ICRISAT)
811A, Road 41, Jubilee Hills,
Hyderabad - 500 033.

Foreword

Climate and weather have directly a pervasive effect on land use, crop quality and its productivity. Climate thus impacts all aspects of our environment and life. Further, climatic variability and climate changes and the occurrence / frequency of extreme weather events are important for the stability of agricultural production and its quality. The thermal and hygric environments are considered as the two main weather variables that determine crop yield, particularly in the rainfed agriculture. To understand the influence of these weather elements, in terms a study of their physical and biological impacts is essential for sustaining our agriculture. In the absence of quantitative climatic data, land use planning, forecasting of weather and climate related research and services by agrometeorologists cannot proceed to suitably assist the farming communities to sustain crop production. Meteorological data are also an essential to supplement the assessment of impacts of land-use sector on the environment and changes in climate. Meteorological observations are therefore needed, at different spatial scales, both for advance planning of farm activities and for real-time interventions in the process of crop production.

The state of Andhra Pradesh contributes about 20 million tons of food (about 8%) to the country's annual grain production. Its 970 km long coast line on the east frequently exposes the state to cyclones and monsoon depressions in the Bay of Bengal. On the southern side of the state, lies a vast rain shadow area. Under such differential climatic conditions, number of eco-climates occur in the state and a variety of crops are grown. Some 55% of the net cultivated area of the state is rainfed. These areas oscillate under different rainfed crops year-to-year in accord with the performance of monsoons. Thus, the productivity of rainfed crops is largely dependent on both the temporal and spatial distribution of rain. Therefore, in order to introduce conservation sustainable agricultural practices, a complete understanding of the length of the growing season and its inter-and intra-seasonal variability together with the incidences of droughts, floods and their probabilities at the micro and meso-scales are urgently needed. These require an input of long-term climatic data from a high density network of meteorological observatories. I understand, that the India Meteorological Department (IMD) collects, assembles and records met-data from some 300 locations in the state. Due to the extreme diversity of agroecologies found in the state the number of meteorological observatories or locations and the available data are not sufficient for micro level planning of agricultural operations. Currently the data are available for a sufficient length of time for analysis at micro (mandal) level for rainfall only. The authors of this monograph have collected carefully, analysed and estimated other parameters of climate (which are available at the district level) and have used appropriate geo-spatial tools to enlarge the observed data to the mandal level. This is truly a painstaking analytic research work; I therefore have no hesitation in complimenting the authors for their efforts in assembling a voluminous meteorological database, putting it in order and analyzing it in such a way so as to serve as a guide for planning activities of various agriculture related sectors.

The work contained in this volume, though of a first approximation nature, is excellent and an unique attempt of agro-climatic analysis at micro and meso levels. I believe, a very useful information has been generated through these studies. It would serve as a pace setter and an example for future climate research. When replicated for other areas, such research can be of great value and assistance in broadening base-line natural resource management work for the introduction of sustaining conservative agriculture production systems.

22nd October, 2013

(S.M. Virmani)

Acknowledgements

Agricultural production in the state of Andhra Pradesh is at the mercy of monsoonal rains during the *kharif* season and cyclones / depressions that visit at harvest very frequently. Climatic information at the micro-level is very much needed in crop planning as well as for day-to-day field operations. Lack of such information for the state has compelled us to source enormous data from various Organizations / Institutions / Departments and Research stations of ANGRAU. We tried to extract information and presented in a simple and practically usable form. We thank Dr. A.K. Sikka, DDG (NRM), ICAR, New Delhi for his keen interest, support and guidance at all stages of the study.

We are thankful to Dr. S.M. Virmani, Former Principal Agroclimatologist, ICRISAT, Patancheru for his critical review of the entire draft and valuable suggestions. We profusely thank Prof. P.S.N. Sastry, Former Principal Scientist (Agromet), IARI and Prof. B.V. Ramana Rao, Former Project Coordinator (Agromet) for their valuable comments /observations at various stages of the work and in the preparation of the document.

We place on record the help/assistance rendered by Dr. G.G.S.N. Rao, Dr. K.V. Rao, Shri. A.V.M. Subba Rao, T. Satyanarayana, N. Manikandan, P. Santhi Bhushan Chowdary, V. M. Sandeep, V. P. Pramod, Miss. N. Pallavi and D. Harini in the analyses.

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Executive Summary

Crop production globally is majorly governed by weather and climate. Challenges to sustain the current production levels are on a rise due to increased climatic variability, occurrence of extreme events because of impending climate changes. For proper planning of the agricultural production systems in a region, therefore a detailed analysis of climatic data/ information is a pre-requisite. For farm level decisions, for risk management, weather information at micro level is needed. Climatic information at micro (*mandal*) level for the state of Andhra Pradesh has not been available hitherto. This study attempts to present an Agroclimatic Atlas for the state of Andhra Pradesh covering all aspects of agrometeorology. It is a first approximation - a model study. It presents an in-depth analyses. As a special feature, it attempts to present a detailed agroclimatic analysis of Anantapur district. The aim of this study is to demonstrate how agroclimatological analysis could form a basis for formulating efficient management of natural resources in the crop planning.

Agricultural scenario of Andhra Pradesh

Amongst cereals, paddy, maize and sorghum are the principal cereal crops of the state. The area under paddy is about 35 lakh ha with a production of 136 lakh tonnes and productivity of 3090 kg ha^{-1}. Maize is the second largest crop with an area of about 8 lakh ha, production of 38 lakh tonnes and a productivity of 4000 kg ha^{-1}. Sorghum which occupied an area of 25 lakh ha in the 1970s, is now grown on about 3 lakh ha. The major grain-legume crops of the state are chickpea, pigeonpea, blackgram and greengram. Productivity of chickpea is around 1200 kg ha^{-1}. Pigeonpea area is about 4.53 lakh ha with a productivity of only about 360 kg ha^{-1}. Inter-annual variability in yields is largely weather driven.

Area, production and productivity of blackgram has varied over the years. Area under green gram has showed a marginal decline in the recent years but production has enhanced due to an improvement in its productivity. Both of these pulses crops are facing threat from better remunerative crops and of the wide scale occurrence of yellow mosaic virus.

Groundnut is the principal oilseed crop grown on 16.5 lakh ha. The production and productivity vary considerably over years due to variations in the amount of distribution of rainfall. Anantapur district grows about 8 lakh ha of the crop; and is the largest groundnut growing district in India.

Sunflower is the second largest oilseed crop grown in the state. There is a large inter-annual variability recorded in the production of castor. Its area and production have consistently declined over the years. Castor is highly sensitive to excess moisture during its flowering and pod development stages. The receipt of pre-monsoon showers regulates area under the castor each year. Similarly, area under sesame is also recording a sharp decline but production has marginally decreased.

Cotton is the principal commercial crop of the state and is cultivated in more than 13 lakh ha. In years of early dry spells during rainy season, more area is devoted to cotton owing to its relatively higher drought tolerance. Chillies is another important commercial crop grown in over 2 lakh ha, but production and productivity of this crop has steeply increased in recent years. A gradual increase in sugarcane production has been noted which is due to an increase in the area under the crop. However, inter-annual variation in the productivity of sugarcane is primarily related to the weather, since large area under the crop is rainfed.

Climate in general

About 63% of the geographical area of Andhra Pradesh is semi-arid, 18% is dry sub-humid (mainly in north coastal districts) and about 15% of the area in *Rayalaseema* is arid. Majority of the *mandals* in coastal districts of Guntur, Krishna and Srikakulam are semi-arid. The entire Anantapur district, *mandals* on the western parts of YSR Kadapa, Kurnool, majority of *mandals* in Mahabubnagar and Nalgonda districts and Peddaraveedu *mandal* of the Prakasam district are classified as arid.

a) Rainfall

Annual normal rainfall of the state is 906 mm, out of which Southwest monsoon (June to September) accounts for 67% and Northeast monsoon (October to December) accounts for 24%. The rest (9% of the rainfall) is received during the winter and summer months. There is a large spatial variability in the distribution of rainfall over the regions of the state. Southwest Monsoon (SWM) is predominant in the *Telangana* region (716mm) followed by the Coastal Andhra (620 mm) and the *Rayalaseema* (407 mm), whereas the Northeast Monsoon (NEM) provides maximum amount of rainfall in the Coastal Andhra area (324 mm) followed by *Rayalaseema* (238 mm) and *Telangana* (129 mm). There is a large difference in annual rainfall received across the districts with East Godavari topping the list (1125 mm), the lowest rainfall is observed in Anantapur district (546 mm). The variability in the rainfall during SWM was found to be highest in Anantapur district (36%) followed by SPSR Nellore (35%) and the least in Vizianagaram (17%). Highest variability in NEM rainfall was observed in Nizamabad (95%) followed by Adilabad (94%) whereas it is relatively stable in SPSR Nellore (33%).

The total annual rainfall is received in 39 to 58 rainy days with a variability of 15%. On an annual basis, the average number of rainy days in coastal Andhra region are 52 followed by 46 in *Telangana* and 39 in *Rayalaseema* regions. Highest number of rainy days are observed in Visakhapatnam and Vizianagaram districts (58 days).

During the SWM season, the state receives 608 ± 177 mm. Adilabad district of *Telangana* receives highest amount of annual rainfall (904 mm). In the coastal region, West Godavari and Srikakulam districts receive high amount of rainfall (725 mm). Lowest rainfall is noted in Anantapur district (322 mm) followed by SPSR Nellore (328 mm). Variability in rainfall over the entire state is high (29%) compared to the national average (11%) or that of southern peninsular region (15%). Lowest variability is seen over Coastal Andhra (26%) and highest in *Rayalaseema* (32%) and it is intermediate over *Telangana* (28%). At the district level, highest variability of rainfall is observed in the Anantapur district (36%) and lowest in Vizianagaram (17%). SWM rainfall in the state is spread on an average over 33 days. Highest number of rainy days are observed in the *Telangana* region (37 days) and lowest over the Ralayaseema region (22 days); and the number of rainy days are intermediate over the Coastal Andhra region (33 days). Khammam and Adilabad districts record maximum number of rainy days (42 days) while, these were least in Anantapur (18 days).

Rainfall during the NEM season for the entire state is 214 ± 129 mm with a variability of 60%. Coastal Andhra receives significant amount of rainfall (304 mm) and *Rayalaseema* receives a fairly good amount of rainfall (232 mm) while, the lowest NEM rainfall is recorded in the *Telangana* region (116 mm). SPSR Nellore district receives abundant rainfall (656 mm) during this season; it is lowest in Adilabad (93 mm).

Trends in time series

Around 85 percent of the *mandals* in the state showed no significant trend in annual rainfall. However, majority of the *mandals* in Medak district showed declining trend in annual rainfall followed by Karimnagar, Mahabubnagar and Nalgonda districts. On the other hand, increasing trend in annual rainfall is observed in many *mandals* of Anantapur, Kurnool, Prakasam and also in few *mandals* of SPSR Nellore, Krishna and Vizianagaram districts. There is no significant increasing / decreasing trend observed in 80 per cent of *mandals*. Most of the *mandals* of the drought-prone districts of *Rayalaseema* region (Anantapur, Chittoor, YSR Kadapa and Kurnool) showed an increasing trend. At the same time, a declining trend is noticed in several *mandals* of *Telangana* region, Prakasam, Guntur and West Godavari districts.

In 17 out of 45 *mandals* of Medak district, a declining trend was observed in SWM rainfall. In Medak 10% of the geographical area showed a strong decreasing rainfall tendency. At the same time, increasing trend in summer monsoon rainfall is observed in large number of *mandals* of Khammam and Visakhapatnam followed by Kurnool and Krishna districts. The trend of number of rainy days during the summer monsoon season showed same pattern as in the case of amount of rainfall. However, a declining trend is evident in about 20 *mandals* of Nalgonda district.

Generally, no significant trend of changes in the amount of rain events has been observed in most parts of the state under both categories (75-100 mm and >100 mm day^{-1}). However, significant increasing trend in 75-100 mm category has been noted in many *mandals* of Krishna, West Godavari, Guntur, SPSR Nellore and Vizianagaram districts. A declining trend is observed in Karimnagar and Medak districts in the 75-100 mm category. In the *Rayalaseema* region, a decreasing trend is also observed in *mandals* like Chintha Kommadinne, S. Mydukur, Yerraguntla, Kadiri, Tadimmarri and Uravakonda only while Rayachoti *mandal* of YSR Kadapa district showed an increasing tendency. For rainfall >100 mm per day category, only 32 *mandals* in the state showed an increasing trend. At the same time, declining trend has been observed in 20 *mandals*.

Rainfall during SWM season significant increasing and declining trends in 75-100 mm day^{-1} category is observed in 33 and 27 *mandals*, respectively. Maximum number of *mandals* showing significant increasing trend is seen in Guntur (6 *mandals*). Declining trend is observed in *Telangana* region particularly in Karimnagar and Adilabad districts. A few *mandals* of Khammam, Warangal and Adilabad districts in the *Telangana* region and West Godavari and Visakhapatnam districts in the coastal region showed significant increasing trend whereas declining trend in some *mandals* of SPSR Nellore, YSR Kadapa, Anantapur, Chittoor and Vizianagaram districts in the >100 mm rainfall category were observed.

No significant increasing or decreasing trend is observed in maximum one-day rainfall in majority of *mandals* (220 out of 280 *mandals*). Increasing and decreasing trends are noted in 30 *mandals* each. High daily rainfall episodes showed an increasing trend mainly over the Coastal Andhra region followed by the *Telangana* region while a declining trend is noted over the *Rayalaseema* region.

A significant increasing trend in maximum 5-day cumulative rainfall has been noted in eight *mandals* and a declining trend is observed only in two *mandals*.

Out of 280 *mandals* analyzed, only 16 showed increasing tendency in mean daily rainfall intensity. On the other hand only two *mandals viz.*, Piduguralla (Guntur) and Gajapathinagaram (Vizianagaram) *mandals* showed a declining trend.

No significant increasing or declining trend has been noted in 93 per cent (260 out of 280) *mandals* analyzed with respect to length of dry spell. An increasing trend has been evident in six *mandals*, out of which three are located in East Godavari district. A declining trend is observed in the length of dry spell in 14 *mandals* out of which 10 *mandals* are located in the *Rayalaseema* region.

There is no significant increasing or decreasing trend observed in the length of continuous wet spells in 90 per cent (250 out of 280) *mandals* in the state. The length of wet spells showed an increasing trend in 22 *mandals* out of which 13 *mandals* are located in the Coastal Andhra region and 9 *mandals* are situated in the Rayalaseeema region. A declining trend is observed only in 8 *mandals*.

In majority of the districts, except Anantapur and SPSR Nellore, the rainy season commences in the 24th SMW and ends by 40th SMW. In Chittoor, SPSR Nellore and Prakasam districts, the rainy season is limited to 38 to 49 SMW. Isolated rainfall events are noted over the entire state during 50 to 20 SMW and the rains get momentum with the onset of monsoon from 21 SMW onwards.

About 445 *mandals* in the state which are majorly spread in Coastal Andhra region, Chittoor district of *Rayalaseema* region and all districts of the *Telangana* region (except Nalgonda and Mahabubnagar) receive annual rainfall in the range of 600-800 mm. An expected annual rainfall in the range from 400 - 600 mm is observed majorly in the interior region of the state. Lowest amount of annual rainfall expected (at 75 per cent probability) occurs in Anantapur district, and also in some pockets of YSR Kadapa, Mahabubnagar and Nalgonda districts.

Majority of the area in the state is exposed to 16 and 24 per cent probability of the occurrence of moderate drought. Moderate drought with probability of 8 to 16 per cent occurs in Srikakulam, Vizianagaram, Visakhapatnam, Khammam, Warangal and Medak districts. Lowest probability of occurrence of drought has been observed in Bobilli *mandal* of Vizianagaram district and the highest probability has been observed in Chigurumamidi *mandal* of Karimnagar district (48%).

Around 80 per cent of the *mandals* in the state show a probability of <2 per cent of occurrence of severe droughts. Probability of 2 to 6 per cent for the occurrence of severe drought has been noted in many *mandals* of Anantapur and Nalgonda districts. Highest probability of severe drought is seen in Y. Ramavaram (29%), Pamarru (18%) *mandals* of East Godavari and Vemanapalli (15%) *mandal* of Adilabad.

Probability for near normal rainfall condition during SWM is above 50 per cent for all 280 *mandals* studied. Probability of 70% and above for near normal conditions has been noted in only one third of *mandals* of Andhra Pradesh (99 out of 280). In the case of moderately dry category, highest probability of 20% and above of rainfall is noted in seven *mandals*. Probability for severely and extremely dry condition to occur has been observed in 42 and 113 *mandals*, respectively. However, probability of occurrence of severely dry conditions is highest (13%) in Kambadur and Kuderu *mandals* of Anantapur district and the probability of extremely dry condition is highest (8%) in Adoni *mandal* in Kurnool district.

Probability of the occurrence of near normal conditions is above 50% during the northeast monsoon season in all the 280 *mandals* studied. *Mandals* in SPSR Nellore district which receive around 60 per cent of annual rainfall during this season, have a probability ranging from 56 per cent (Venkatagiri *mandal*) to 71 per cent (Atmakur *mandal*) of recording normal rainfall.

Length of Growing Period (LGP)

The LGP occurs between 120-150 days in the districts of Adilabad, Nizamabad, Karimnagar, Medak, Warangal, Ranga Reddy, Khammam, Nalgonda, Mahabubnagar, Kurnool and Prakasam. LGP of >180 days is observed in Srikakulam, Vizianagram, Visakhapatnam and parts of East and West Godavari, Chittoor and SPSR Nellore districts. It is in the range of 150 to 180 days in Krishna, Guntur, parts of Chittoor, SPSR Nellore, Khammam, East and West Godavari districts. The LGP ranges between 90-120 days in parts of YSR Kadapa and Anantapur districts. However, in majority of the *mandals* of Anantapur district, the LGP is < 90 days.

In 8 out of 22 districts of the state, the growing season commences generally during 25th SMW and in the remaining districts, the growing season commences during 26th to 29th SMW. A delayed commencement by 30th SMW is noted in SPSR Nellore, Prakasam and Anantapur districts.

Growing season terminates early in most of the *Telangana* districts (in 43 to 44 SMW) compared to coastal districts (in 46 to 48 SMW). Crop growing season extends by two weeks on an average with a corresponding increase in water holding capacity of the soil by 50 mm. On an average, the length of growing season is longest in coastal districts of the state (22 weeks), followed by *Rayalaseema* (19 weeks) and the districts in *Telangana* (18 weeks) where soils have a water holding capacity of 50 mm. The figures for soils having 100 mm water holding capacity are 25, 21, 20, respectively. For soils having 150 mm water holding capacity the average duration for coastal, *Rayalaseema* and *Telangana* districts are 27, 22 and 22 weeks, respectively. In soils having 200 mm water holding capacity, the length of growing season on the average are 30, 23 and 24 weeks in Coastal, *Rayalaseema* and *Telangana* districts, respectively.

b) Other climatic elements

Mean annual temperature of the state is 33.2°C. A peak in temperature occurs during summer season (37.4°C) and the lowest temperature occurs during the NEM season (30.5°C). Average temperatures are ± 33.1°C during SWM season. Coastal Andhra region experiences relatively low temperatures during winter and summer seasons but higher temperatures during SWM and NEM seasons compared to the two other regions of the state. Highest temperatures (34.5 to 35.5°C) are observed in the northern parts of Adilabad and eastern parts of the Kurnool district.

The state as a whole experiences a minimum temperature of 22.4°C on an annual basis. However, there are regional differences. The coastal region experiences higher temperatures (23.9°C) compared to the *Telangana* region (21.4°C). East Godavari district records highest annual minimum temperatures of 24.9°C whereas Medak (20.0°C) district experiences relatively cooler temperatures.

On a monthly basis, state as a whole experiences high morning humidity during October (84%) and least humidity is recorded during May (66%).

The mean annual wind speed for the entire state is 6.7 kmph with *Telangana* region recording highest average wind speed of 7 kmph. Coastal region is relatively calm with an average wind speed of 6.3 kmph. June is the month with high wind conditions for the entire state (10.2 kmph).

Mean annual number of hours of bright sunshine for the state are 7 hrs/day with *Telangana* (7.3 hrs/day) receiving sunlight for a longer period. Anantapur (8.1 hrs/day) is the brightest district and Srikakulam (5.7 hrs/day) is the dimmest. February month is the month with longest days (9 hrs/day) and July is the month of days with a shorter day length (4.4 hrs/day). Srikakulam district receives sunlight for the shortest period of 2.8 hrs/day in the month of July.

Average total annual evaporation in the state is 1945 mm. Evaporation in the *Rayalaseema* region is the highest (2357 mm) and it is lowest over Coastal region (1634 mm). Amongst the districts, Anantapur ranks first with an annual evaporation of 2674 mm and least evaporation is recorded in Warangal (1255 mm). May is the month with maximal evaporation. The mean total evaporation for the month of May is 251 mm for the entire state with highest recorded in Medak (363 mm) and the least evaporation occurs during May is observed in Warangal (146 mm) district.

c) Agrometeorological production constraints and opportunities

Identification of areas prone to delayed monsoon thus suitable for the promotion of short duration paddy cultivars to tackle planting of over-aged seedlings in tankfed areas. Use of hydrological models coupled with seasonal rainfall forecast of monsoon has been observed to help in giving advance information on the schedule of water release. By using basin models, the areas likely to be inundated can also be identified. Mapping of the areas prone to frequent floods with the help of historic rain data aids in the design, development and maintenance of appropriate drainage systems in the agricultural regions.

In the cotton growing tracts of Andhra Pradesh, advance information with respect to the late arrival of monsoons could help in the selection of cultivars / cropping systems and rescheduling of fertilizer dosages / application and the adoption of soil conservation measures. Information on possible break in monsoons would also help in assessing the likely buildup of abiotic stresses in cotton. High incidence of boll worm (or *spodoptera*) is likely under such situations and agromet advisories could help in the taking up prophylactic measures. Any information on the impending early monsoon withdrawal could potentially help the farmers in rescheduling the fertilizer applications or resorting to foliar nutrient sprays. During high rainfall episodes, and prolonged wet spells are expected, cotton crop is sensitive to high humidity when boll rot occurs; therefore prophylactic measures could be taken up if timely and precise agromet advisory system has been developed and in place.

Information on the high probability of break in monsoon conditions in grain legumes growing areas can assist in developing agromet advisories on intercultural operations, thinning out and vigorous adoption of soil moisture conservation practices. In case of prolonged delay in the onset of southwest monsoons, farmers resort to sowing of pulses on the receipt of rains, late in the season. In such situations, advisories on the likely incidence of biotic stress are crucial. For example, sowing of chickpea in the month of September exposes the crop to *sclerotium* collar rot.

Seasonal agromet advisories are of great assistance in the process of selection of appropriate cultivars of groundnut and other oilseed crops. If onset of monsoon is delayed or sufficient rains have not been received till July, alternate crops to groundnut can be suggested, hence seasonal weather forecasts are vital to minimize the losses at farm level. Break monsoon conditions create nutrient deficiency in oilseeds and early information on mid-season dry spell could certainly assist the adoption of timely corrective measures before nutrient deficiencies occur.

In the case of sugarcane, its yields are affected by both the deficit or excess of moisture and lack of rainfall during July and August results in a substantial reduction in cane yield. Application of trash mulching @ 3 t ha^{-1} during dry spells improves the cane yields. Like-wise, the crop when subjected to water logging affects the sucrose content. It is reduced, thus decreasing the recovery of sugar. High winds lodge the crop which depresses juice sucrose and cane weight decreases as well. All these field problems can be addressed by proper and timely availability of agromet advisories.

During break monsoon situations a complex of sucking pest increasingly attack chillies and the crop undergoes nutrient and moisture stress. Issue of agromet advisories well in advance, would facilitate farmers to adopt intercultural operations to conserve soil moisture, and take-up foliar application of nutrients to correct any deficiency. If the onset of monsoon rains are considerably delayed, then advisories on the methods of sowing and appropriate selection of cultivars to be planted can help to sustain the yield at acceptable levels.

Agroclimate of Anantapur - An intensive analysis

A detailed in-depth analysis of the Anantapur district was carried out to its agroclimatic features for an efficient management of its natural resource endowments. Average annual rainfall of Anantapur is 546 mm with a CV of 24% and PET is 2140 mm. Thus, with an aridity index of -73.6, the district is classified as arid. Normal rainfall during SWM and NEM seasons are 338 mm and 156 mm, respectively. The LGP ranges between 91 to 161 days with eight *mandals* having LGP in the range of 91 to 121 days. Twelve *mandals* show an increasing trend in annual rainfall. Out of 41 years, the rainfall during SWM season was near normal in 13, deficit in 16 and was in excess in 11 years. During SWM season, a rainfall on 323 mm normally occurs in 18 days with a coefficient of variability of 24%, and during NEM season there are nine rainy events, on average, with a variability of 35%. Normally each rainfall event during SWM season produces 18 mm rainfall, which is insufficient to bring the top 45 cm of soil to field capacity. The variability in annual rainfall in the recent decade (2001-2010) compared to the previous decade (1991-2000) showed an increase in the north western parts of the district. Differences in variability of June, July and September rainfall were observed in various *mandals* in the recent decades. In Uravakonda *mandal* a decreasing trend in heavy rainfall events (75-100 mm category) has been noticed. Out of 63 *mandals*, the probability of occurrence of mild droughts is very low (-10%) in 10 *mandals*. Probability of getting 2 to 3 drought years in a decade has been recorded in 25 *mandals*. In six *mandals* the probability of occurrence of severe drought is low (10%).

The key to realizing stable yields of groundnut in Anantapur is the distribution of rainfall rather than its total amount. The peg penetration and pod development stages are highly sensitive to dry spells and hence distribution of rains becomes important. The effect of the length of dry spells at different growth stages on groundnut pod yield at Anantapur has indicated that yields decline if the moisture deficit exceeds for three weeks or more in the early vegetative stage of the crop (0-35DAS). The impact of drought is more pronounced during the start of pegging and seed development (51-85 DAS) stages. Pod yields decline drastically in years when the length of dry spell exceeded 30 days at this stage. Frequent failure of monsoon rains during these critical periods is the main cause of the failure of groundnut crop in the district. An amount of total rain of 350 mm during its growing season appears to be critical for obtaining minimal yield of 350 kg ha^{1}. When the seasonal rain is above the 350 mm threshold, the probability of realizing an yield upto 1 ton ha^{-1} or more is ensured in 50% of the year. It appears that during some years, despite high seasonal rainfall, lower yields were realized which signifies improper distribution of rainfall. Of late, the August rainfall in the district has become somewhat uncertain. Cultivars which can tolerate prolonged stress during its re-productive stage need to be bred urgently. In Anantapur district, either Spanish bunch or Virginia bunch types of groundnuts are largely cultivated. These have a duration of 110-135 days. The currently cultivated groundnuts cultivars in vague, can withstand 4 weeks of continuous dry spell.

Research must be undertaken for the development of genotypes that can withstand prolonged dry spells without foregoing pod yield and biomass as both are economically important. Development of early maturing (90 days) drought-tolerant groundnut cultivars and also those suitable for late-sown conditions for areas receiving delayed monsoon may be targeted. Suitability and economic viability of groundnut-millet; groundnut-pulses; groundnut-castor and similar cropping systems need to worked out. Research on development of groundnut-based integrated farming system models with small ruminants is also needed to bring stability, income and livelihood resilience to small holders/ marginal/ SC/ST farmers. There is lot of scope for the promotion of cultivation of short duration chickpeas in the vertisol (black soils) areas. The latest cultivar 'JAKI 9218' which is very popular and high yielding may be promoted in the district.

The groundnut (intercropped with pigeonpea and caster) -chickpea cropping system. It is ideal for the district although the district receives a mean annual rainfall of about 566 mm, and on an average it has 5 run-off events per annum. Under such a situation, there is a need for harvesting the rainwater and its judicious use during critical crop growth phases. Farm pond technology has been developed and successfully demonstrated in Anantapur district by several agencies. This technology has been shown to benefit the farmers to provide supplemental irrigation to the crops at critical growth stages when drought occurs. Improvements should also be made in on-farm water management techniques to reduce ground water draft by pumping. This can be achieved by improved irrigation application methods. Adoption of drip and micro sprinkler irrigation systems is important. In case of the availability of excess surface runoff in localized depressions in the agricultural areas, sub surface recharge structures such as recharge shafts or recharge cavities can be adopted for better ground water recharge. About 10-15 blocks in the district are also suitable for the cultivation of clusterbean for gum production. Trials carried out by the Arid-legumes project in the past have shown that 600-800 kg ha^{-1} yield can be obtained under rainfed conditions.

However, due to the lack of market support infrastructure this initiative could not go forward. Now, a time bound action plan needs to be chalked out for promoting clusterbean cultivation for gum production. In recent years, castor has been cultivated in some *mandals*. The performance of the crop during *rabi*-summer is very good and it has paid good dividends. In 15-20 blocks, promotion of castor (varieties in *kharif* and hybrids in *rabi*) can give higher returns than groundnut either as sole or as an intercrop with cluster beans. The area under chickpea is also on the rise especially in *mandals* with (vertisols) black cotton soils. The possibilities for the promotion of high value medicinal and aromatic plants like Aloe vera, lemon grass, and such other crops along with suitable marketing support may be explored. Similarly, introduction of selected horti-pastural systems and horti-agri systems must be explored depending on agro ecological condition.

1. General information

Andhra Pradesh abuts the south-eastern coast of India. It is its fourth largest state in area and is fifth in population. Situated between 12°41' and 22°N latitude and 77° and 84°40'E longitude, the state is bordered by Maharashtra state in the west/northwest, Chhattisgarh and Odisha states in the north, the Bay of Bengal in the east. The state of Tamil Nadu lies to its southeast and the Karnataka state to its southwest (Fig.1). The state has a coastal line of 972 km and is prized with two major rivers, the Godavari and the Krishna.

1.1. Land use pattern

The total geographical area of the state is 275.04 lakh ha. In 2008-09 the net sown area was 39.9%; 22.6% was under forests; 10.6% under current fallows, 9.6% was under non-agricultural uses, and 7.6% area constituted barren and uncultivable lands (Table 1). The net area sown declined by 3.4% from the year 1966-67 and the area utilized for non-agricultural uses steeply increased by 28.8%.

Table 1: Land use pattern of Andhra Pradesh

Category	1966-67	1976-77	1986-87	1996-97	2005-06	2006-07	2007-08	2008-09
Geographical Area	275.1	275.1	275.1	275.1	275.1	275.1	275.1	275.1
Forest	61.2	63.8	58.4	62.5	62.0	61.1	62.1	62.1
Barren & Uncultivable land	20.8	22.9	22.7	20.8	20.8	21.0	20.6	20.6
Land put to Non Agricultural uses	20.6	21.0	22.6	24.7	26.2	25.9	26.4	27.4
Cultivable Wastes	13.7	9.6	8.6	7.2	6.9	7.0	6.6	6.5
Permanent Pastures	11.6	9.7	8.8	7.6	6.8	6.0	5.7	5.7
Land under Misc	3.1	2.7	2.6	2.5	2.8	3.2	3.1	3.0
Other fallow lands	8.7	12.2	15.0	15.5	16.2	15.8	15.0	14.9
Current Fallow lands	21.7	26.5	35.2	24.4	24.3	31.7	27.2	26.2
Net Area Sown	113.4	106.0	100.5	108.3	108.4	102.3	108.4	108.9

Source: *Directorate of Economics & Statistics, Govt. of Andhra Pradesh, Hyderabad, 2011*

1.2. Soils

Andhra Pradesh has a consortia of soils ranging from coarse coastal sands to highly fertile deltaic alluviums. Over 66% of the cultivated area is under red soils (Alfisols) and these are confined mostly to *Rayalaseema* districts. These soils have a low nutrient status and can be sub-classified as (a) *Dubba* soils (loamy sands to sandy loams) (b) *Chalkas* (sandy loam soils) (c) sandy clay loams (d) loams including silty soils (e) deep loamy sands and (f) sandy loams with clay subsoil. *Chalkas* occur mostly in the *Telangana* districts while red loams combined with sands are present in the upland regions of coastal districts.

About 25% of the cultivable area of the state is covered by black (Vertisols/Vertic) soils also locally called as *Regurs*, which are generally associated with poor drainage. These are of two types. The first type are those soils that have developed *in-situ* soils, in the coastal districts and parts of *Telangana* and *Rayalaseema*. The second type of these are found vertisols are transported soils, these mostly occur in the valley areas of the slopes, and are rich in calcareous material. The Vertisols developed *in-situ* are generally heavy in texture, and have high salt concentration.

Coastal sands occupy only 3% and 1% of the total area is under laterite soils and these occur in certain pockets. The alluvial loamy clay soils (entisols) are found in Krishna and Godavari deltas and cover 5% of the total cultivated area.

1.2.1. Soil texture

Soil texture indicates the relative proportion of primary particles of sand, silt and clay. The surface layer of a soil to a depth of about 25 cm is the layer that is most used by crops and plants. The surface soil textural class provides a guide to understanding soil-water retention and availability, workability, nutrient-holding capacity, infiltration, drainage, physical and chemical behaviour, microbial activity and crop suitability.

The mapping units were grouped by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) into 25 associations of surface soil textural classes and the surface soil textural classes, are presented in Fig. 2. About 39 per cent of the area of Andhra Pradesh has predominantly clayey soils. They have high potential for nutrient and available-water holding capacity. About 42 per cent of the area has loamy soils and about 10 per cent sandy soils. About 8 per cent has predominantly rocky and other miscellaneous land types.

1.2.2. Soil Depth

Depth of the soil controls the effective rooting depth of plants, and in accord with its texture, mineralogy and gravel content, the capacity of the soil profile to hold water and supply plant nutrients is determined.

The soil depth map is given in Fig. 3. About 14 per cent of the area of Andhra Pradesh has very deep (>150 cm) soils, 30 per cent has predominantly deep (100-150 cm) soils, 26 per cent has predominantly moderately deep (75-100 cm). These total about 70 per cent and have high potential for growing all agro-climatically adapted annual and perennial crops. About 6 per cent of the area has predominantly moderately shallow (50-75 cm), and about 14 per cent shallow (25-50 cm) and 2 per cent extremely shallow (10-25 cm) soils. About 8 per cent of the land has predominantly rocks and other miscellaneous types of lands.

1.2.3. Soil Slope

Slope refers to the inclination of the surface of the land with respect to a reference point. It is defined by gradient, shape and length, and is an integral part of any soil as a natural body. The length and gradient of slope influences soil formation and soil depth and as such affects land use and land development.

The soils of Andhra Pradesh have been grouped by NBSS & LUP under 13 associations of slope classes, the slope map is given in Fig. 4. About 13 per cent of the area of Andhra Pradesh has soils occurring on level to nearly level lands (0-1%), 44 per cent on very gently sloping lands (1-3%) and 15 per cent on gently sloping lands (3-8%). These lands constitute about 73 per cent which can be safely used for arable farming. About 15 per cent of the area has moderately sloping (8-15%) lands, about 15 per cent with moderately steeply sloping (15-30%), about 2 per cent with steeply sloping (30-50%) lands and 8 per cent under rock land and other miscellaneous lands. These together constitute about 26 per cent which can be used for forestry, agroforestry, silvi-pastoral systems, quarrying, wildlife and recreation.

1.2.4. Soil Drainage

Soil drainage refers to the rate of removal of rain water or added water from the soil by flow through the soil to underground storage and by runoff. Drainage influences the soil-air-water relationship in soils and determines the availability of oxygen and nutrients to plants. Data on soil drainage is essential for determining the suitability of soils for irrigation, for different crops and for crop planning.

The soil map units were grouped into 15 associations of drainage classes by NBSS & LUP and the soil drainage map is given in Fig. 5. About 47 per cent of the area of Andhra Pradesh is dominated by well drained soils, 21 per cent by moderately well drained soils. The soils which have a potential for growing a cultivar of crops constitute about 68 per cent; about 8 per cent area has imperfectly drained and poorly drained soils and about 15 per cent somewhat excessively drained soils. About 8 per cent has rock land and other miscellaneous land.

1.2.5. Available-water capacity of soils

Available-water capacity (AWC) of soils is dependent upon the amount, intensity and distribution of rainfall, infiltration and permeability and type of clay minerals, texture, depth and gravel content. Classes of soil available-water capacity (AWC) are based on the ability of the soil column to retain water between the tensions of 0.33 k Pa and 15 k Pa to a depth of 100 cm soil or the entire column if the soil is shallow. The areal extent of soils in the 16 associations of AWC classes is given in map (Fig. 6). About 15 per cent of the area of Andhra Pradesh has soils with very high AWC (>200 mm m^{-1}) and 6 per cent with high AWC (150-200 mm m^{-1}) which means about 21 per cent area has a potential for growing long duration crops. About 35 per cent has medium AWC (100-150 mm m^{-1}), 13 per cent low AWC (50-100 mm m^{-1}) and about 22 per cent very low AWC (<50 mm m^{-1}). About 8 per cent of the area is dominated by rock land and other miscellaneous lands.

1.3. Climate in general

Climate of the Andhra Pradesh state has been evaluated by Thornthwaite and Mather (1955[1]) water balance approach. The state predominantly is semi-arid tropical with 63% of the geographical area falling under semi-arid climate. About 18% of the state's area is dry sub-humid which is mainly located in north coastal districts, and about 15% of the area located in *Rayalaseema* is arid (Fig. 7). At district and *mandal* level for crop planning, it is observed that majority of the *mandals* in coastal districts of Guntur, Krishna and Srikakulam are semi-arid. However, the entire Anantapur district is arid. Arid climatic conditions are also observed in *mandals* located on the western parts of YSR Kadapa, Kurnool districts and in majority *mandals* of Mahabubnagar and Nalgonda districts and Peddaraveedu *mandal* of the Prakasam district. Dry sub-humid climatic conditions are noticed in coastal region (18% of the state area) *viz.,* Visakhapatnam, East & West Godavari districts and in majority of the *mandals* in Vizianagaram, Srikakulam, SPSR Nellore and northern parts of Khammam and Warangal districts. Among the coastal districts of the state, only Prakasam district entirely falls under semi-arid climate. Majority of the *mandals* in Krishna, Guntur, Karimnagar and Adilabad districts experience semi-arid climate with a few *mandals* having a dry sub-humid climate. Moist sub-humid and humid B1 climatic type is observed only in Visakhapatnam. Munichigput *mandal* is the only *mandal* having humid B1 climate with highest annual rainfall in the state. Two *mandals viz.,* Gudem Kothaveedhi and Gangarajau Madugula can be classes as moist sub-humid climate type.

Out of about 110 m ha of net sown area, 55% is rainfed. Annual normal rainfall of the state is 906 mm, out of which Southwest monsoon (June to September) accounts for 67% and Northeast monsoon (October to December) accounts for 24%. The rest (9% of the rainfall) is received during the cool and summer months. There is a large spatial variability in the distribution of rainfall over the three regions of the state. Southwest monsoon is predominant in the *Telangana* region (716mm) followed by the Coastal Andhra (620 mm) and the *Rayalaseema* (407 mm), whereas the Northeast monsoon provides high amount of rainfall in the Coastal Andhra area (324 mm) followed by *Rayalaseema* (238 mm) and *Telangana* (129 mm). There is little significant spatial variability in the distribution of rain during cool winter and hot season amongst the three regions.

[1] Thornthwaite, C.W. and Mather, J.R. 1955. The Water Balance. Publications in Climatology, Laboratory of Climatology, Vol.8, No.1, 104 pp.

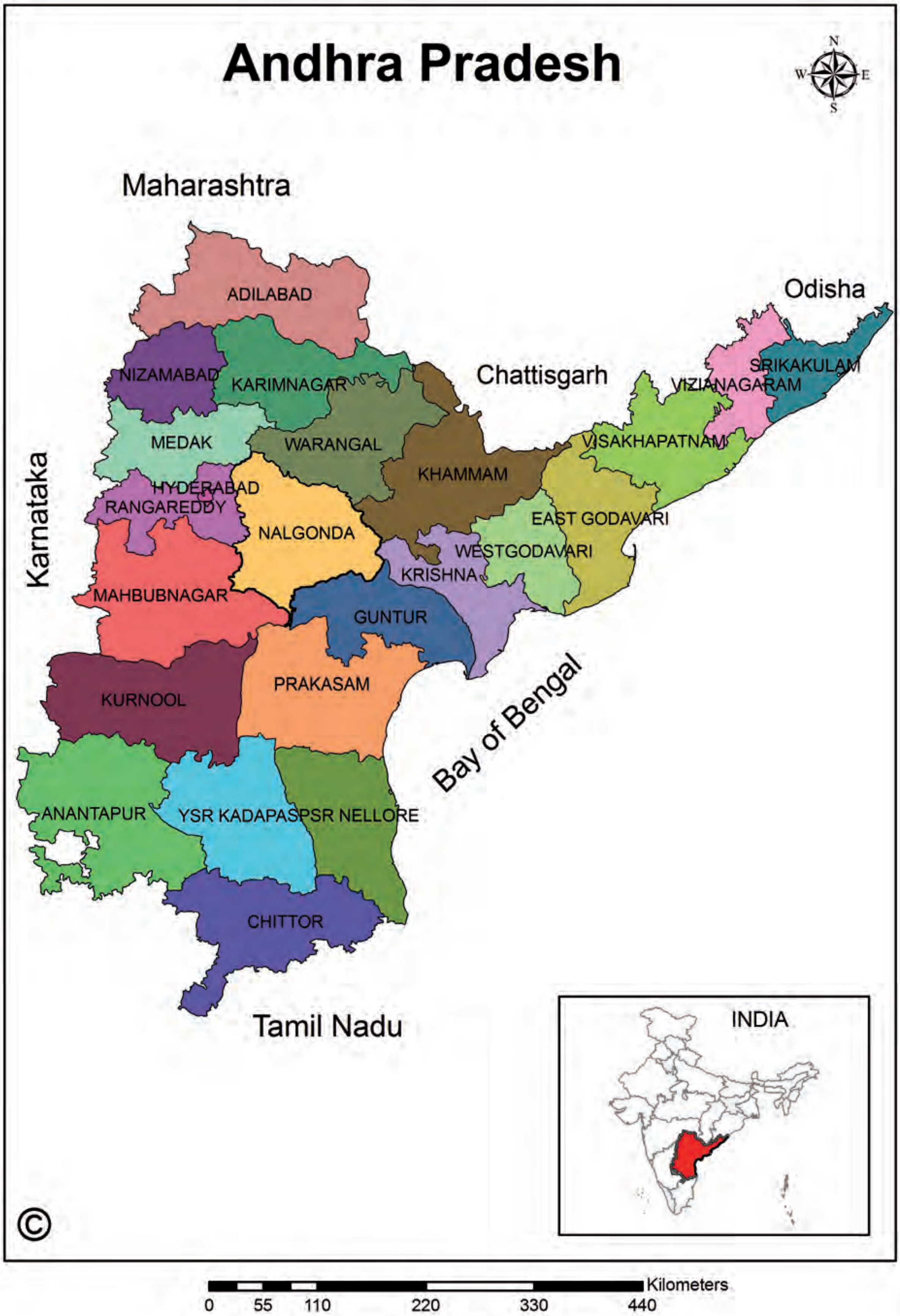


Fig. 1: Map showing district boundaries in Andhra Pradesh

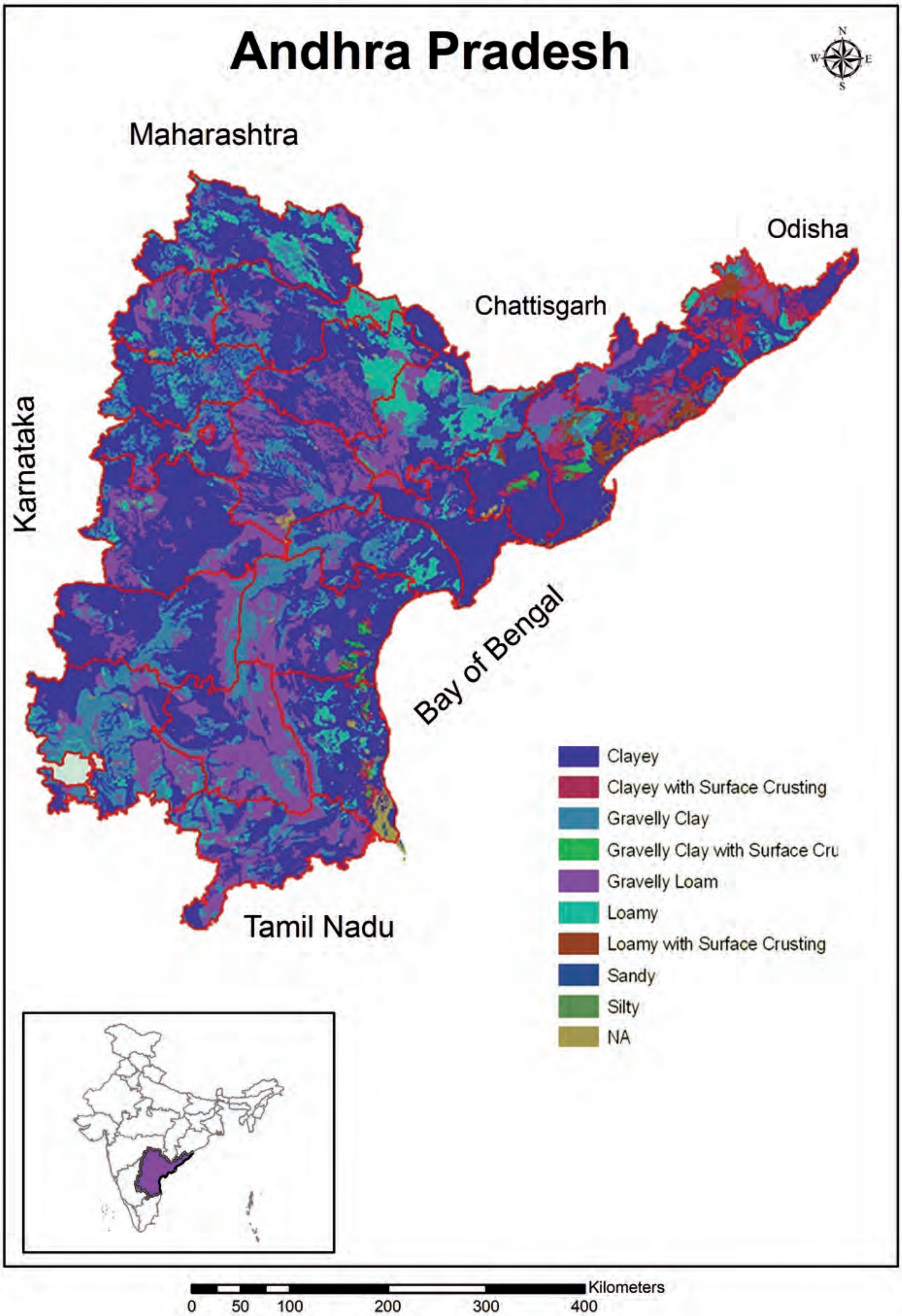


Fig. 2: Soil textural class map of Andhra Pradesh

(Source: NBSS & LUP)

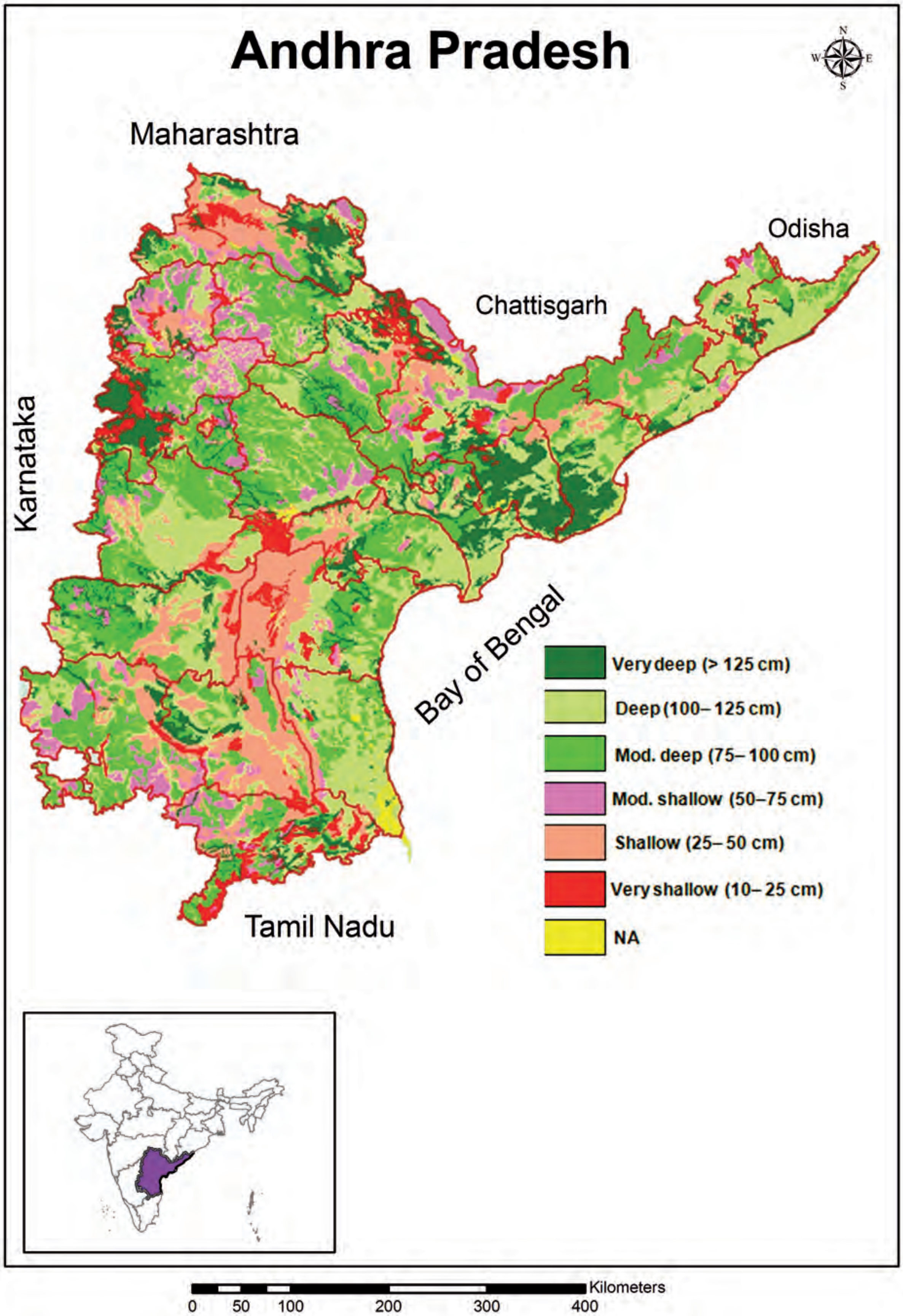


Fig. 3: Soil depth (cm) map of Andhra Pradesh

(Source: NBSS & LUP)

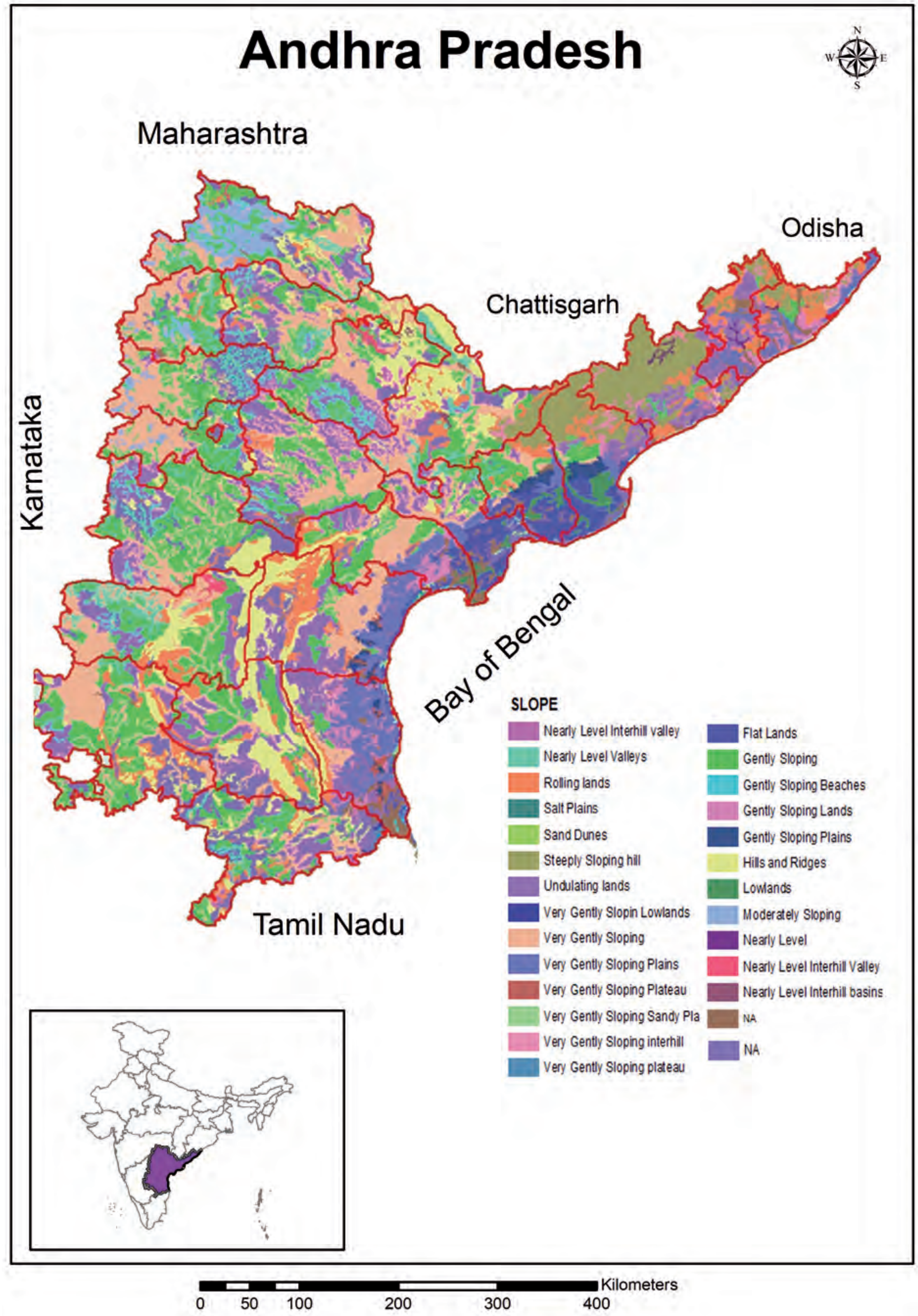


Fig. 4: Soil slope (%) map of Andhra Pradesh

(Source: NBSS & LUP)

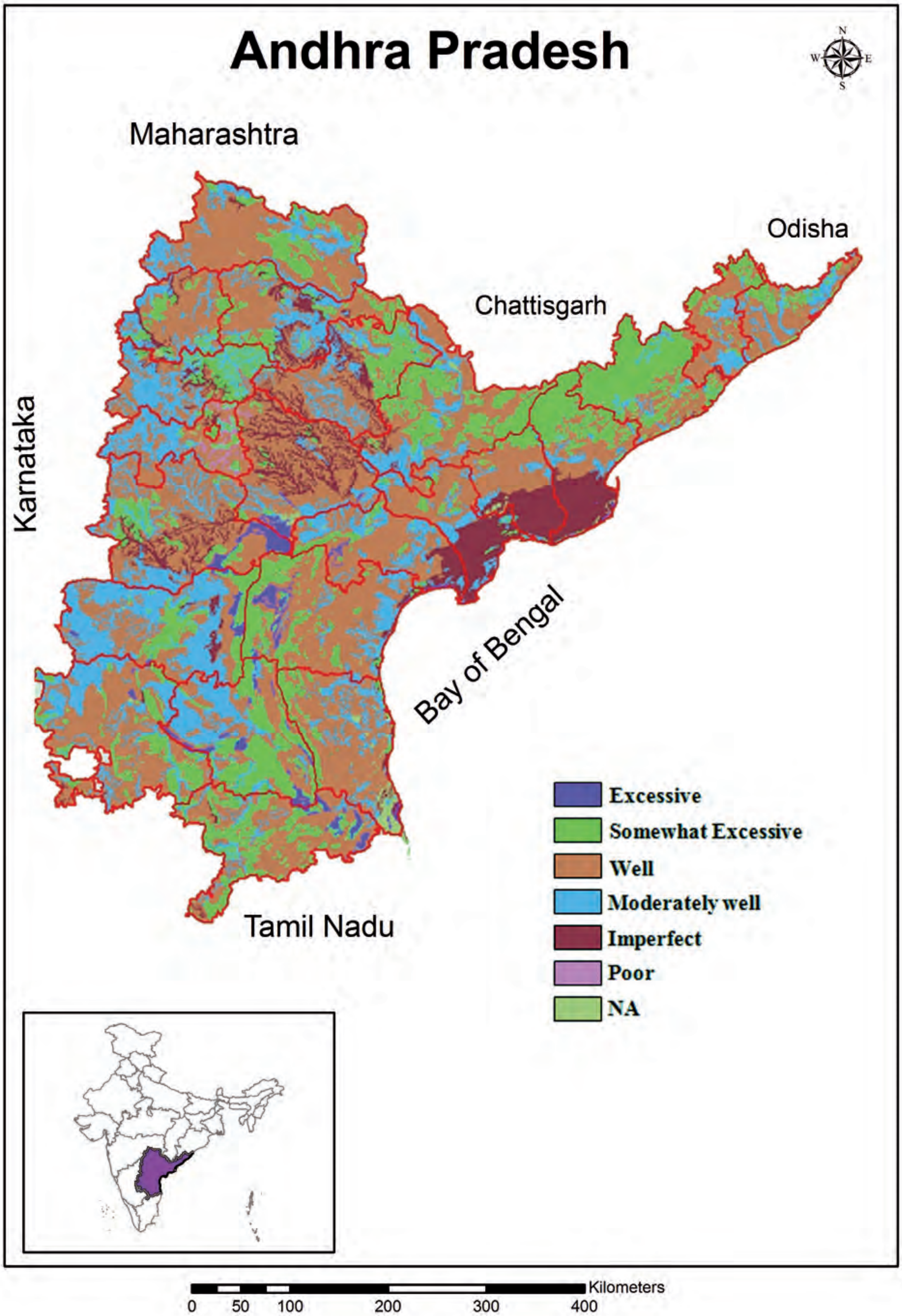


Fig. 5: Soil drainage map of Andhra Pradesh

(Source: NBSS & LUP)

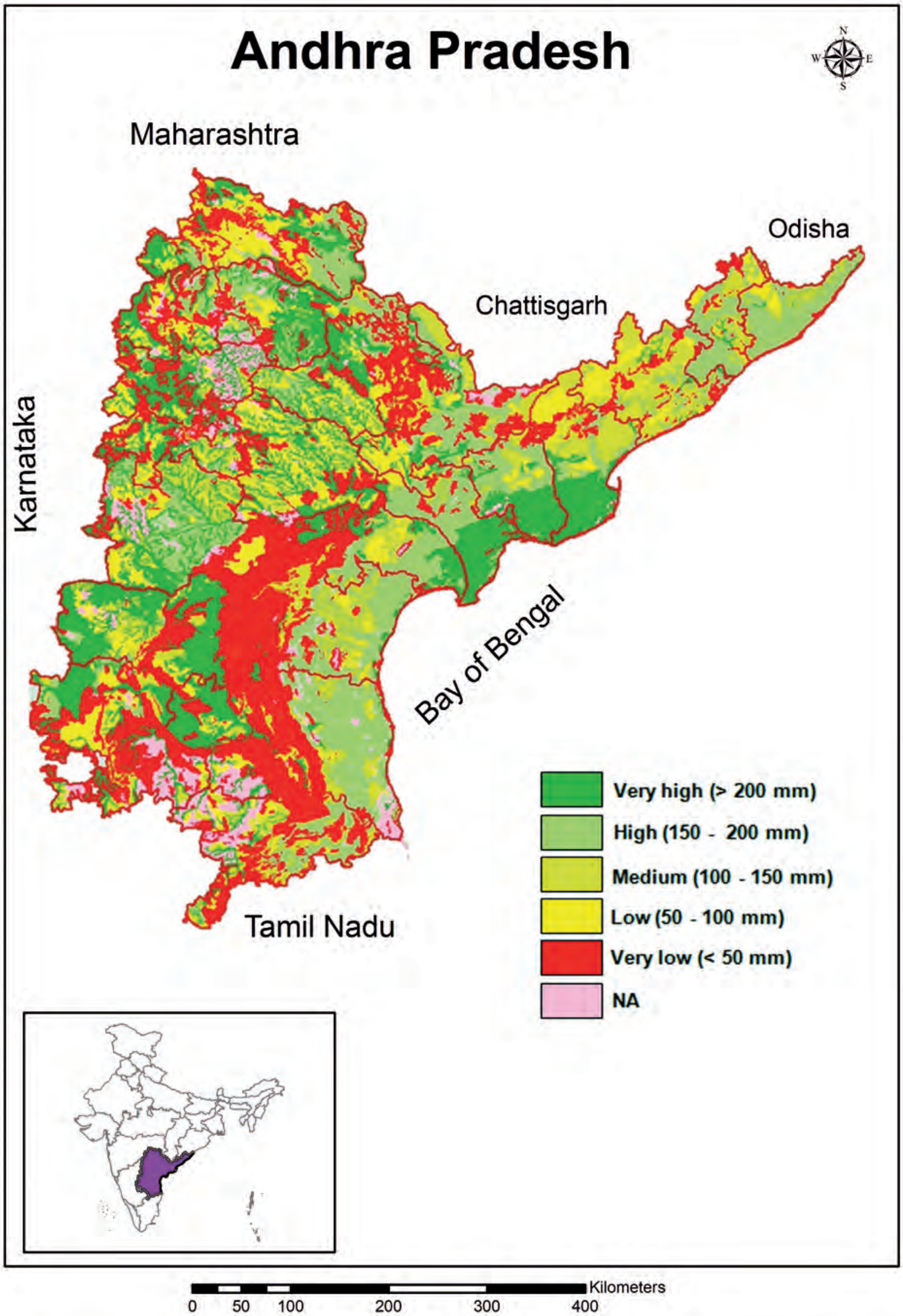


Fig. 6: Available Soil Water Content (mm) map of Andhra Pradesh

(Source: NBSS & LUP)

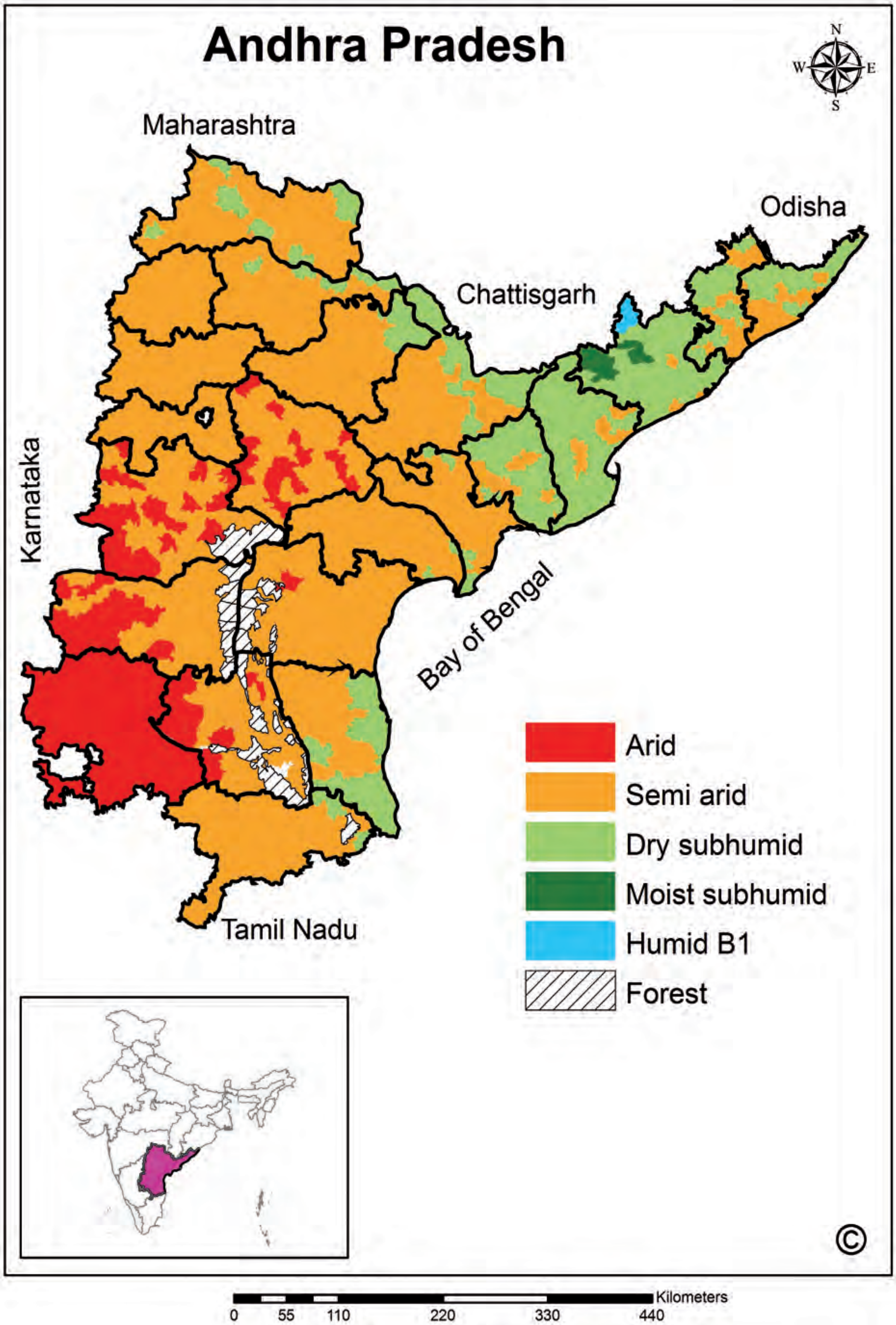


Fig. 7: Regions having different climatic types

2. Agroclimatic zonation

An agro-climatic zone can be defined as a spatial unit in terms of its major climate and the zone's suitability for crops and their cultivars. An ecological region is an area of the earth's surface characterized by distinct ecological responses to macro-climate, as expressed by landscape, soil orders, natural vegetation, flora + fauna, and aquatic systems (after FAO, 1996[2]). Several attempts have been made in India to delineate major agroclimatic/agro-ecological regions with respect to soils, climate, physiography and natural vegetation at macro-level, planning agricultural development programs on a more scientific basis. Some of these are reconstituted here (for ready reference):

A. Agro-climatic Zones under NARP
B. Agro-ecological regions by the NBSS & LUP
C. Agro-ecological regions by the ICAR
D. Agro-climatic regions by the Planning Commission

2.1. Agro-climatic Zones under NARP

The Indian Council of Agricultural Research (ICAR) has divided the country into 131 agro-climatic zones essentially based on climate, soils, and existing cropping patterns of each state as a unit. The agriculture planning for each zone is supported with the research and recommendations of a Regional Agriculture Research Station set up within the particular zone. Andhra Pradesh state has been divided into nine agro-climatic zones (Table 2).

The geographical distribution of all the agro-climatic zones is depicted in Fig. 8. The general agro-climatic features of different zones are presented in Table 3. Relatively higher altitude (tribal zone) receives highest rainfall in the state and generally rainfed crops are grown.

Table 2: Agro-climatic zones of Andhra Pradesh

Name of the Zone	Districts	Head quarters	Geographical area (lakh ha)
North Coastal	Srikakulam, Vizianagaram, Visakhapatnam	Anakapalle	18.5
Godavari	East Godavari, West Godavari	Maruteru	17.5
Krishna	Krishna, Guntur, Prakasam	Lam	37.7
Southern	Chittoor, YSR Kadapa, SPSR Nellore	Tirupati	41.7
Northern *Telangana*	Karimnagar, Nizamabad, Adilabad	Jagtial	35.5
Central *Telangana*	Warangal, Khammam, Medak	Warangal	30.6
Southern *Telangana*	Mahabubnagar, Nalgonda, Ranga Reddy (+ Hyderabad)	Palem	39.3
Scarce Rainfall	Kurnool, Anantapur	Nandyal	36.2
High Altitude & Tribal Areas	High Altitude & Tribal Areas of Srikakulam, Visakhapatnam, East Godavari, Khammam and Adilabad districts	Chintapalli	18.0
Total			**275.0**

[2] FAO, 1996. Agro-ecological zoning-Guidelines. FAO Soils Bulletin 73, FAO, Rome, Italy

Table 3: Agro-climatic features of various zones in Andhra Pradesh

Features	Krishna Godavari Zone	North coastal Zone	Southern Zone	Northern Telangana Zone	Southern Telangana Zone	Scarce rainfall Zone	High altitude and tribal area Zone
Geographical extent	East Godavari, West Godavari, Krishna, Guntur, parts of Khammam	Srikakulam, Vizianagaram, Vishakhapatnam districts and upland belt of East Godavari	SPSR Nellore, Chittor and parts of YSR Kadapa and Anantapur	Adilabad, Karimnagar, Nizamabad, parts of Medak, Nalgonda, Warangal and Khammam.	Ranga Reddy, Mahabubnagar (except the southern border), Nalgonda (except Southeast border), north western part of Warangal and southern part of Medak districts	145 *mandals* in Kurnool, parts of Anantapur, YSR Kadapa, Prakasam and Mahabubnagar	40 *mandals* in Srikakulam, Vishakhapatnam, East Godavari and Khammam districts
Annual Rainfall (mm)	800 to 1110	1060	700 to 1050	900 to 1150	700-900	500 to 750	1245 to 1288
Soil type	Deltaic alluvial, deep and medium black soils, red and red loamy soils and coastal sands	Alluvial, coastal sand and lateritic soils	Red loamy	Red chalka soils	Red sandy, red earths and medium black soils	Black soils, red earths with loamy sub-soil, red sandy soil and problem soils	Red soils
General soil fertility							
Available Nitrogen (kg ha^{-1})	Less than 272	272 to 544	272 to 544	272 to 544	272 to 544	Less than 272	272 to 544
Available Phosphorus (kg ha^{-1})	11.2 to 22.4	11.2 to 22.4	Below 11.2	Below 11.2	11.2 to 22.4	Below 11.2	11.2 to 22.4
Available Potassium (kg ha^{-1})	120 to 280	120 to 280	120 to 280	More than 280	120 to 280	More than 280	120 to 280
Crops	Paddy, blackgram, greengram, pigeonpea, sugarcane, seasmum, tobacco, chillies, cotton, banana, mango	Paddy, millets, sugarcane, groundnut, gingelly and mesta	Groundnut, Paddy, sugarcane, ragi, bajra, pigeonpea	Paddy, sugarcane, sorghum, pulses, maize, cotton, groundnut, turmeric and chillies	Sorghum, castor, Paddy, groundnut, bajra, pigeonpea, horsegram, ragi, greengram, maize and seasmum	groundnut sorghum, foxtail millet, Paddy, cotton, coriander and pearl millet	Paddy, millets, mesta, niger, tuber crops, Tea, coffee and other plantation crops

2.2. Agro-ecological Zones

The National Bureau of Soil Survey and Land Use Planning has delineated the country at National level into different agro-ecological regions based on soils, physiography, length of growing period (LGP) and bioclimate. At state level, agro-ecological zonation is done considering soil family association (1:250000 scale), landform, annual rainfall at sub-divisional level and LGP. Isolines are depicted at an interval of 15-day. The agro-ecological zonation maps prepared for the entire country have been as the basis to extract zones for the Andhra Pradesh state by super-imposing GIS maps of district boundaries. The base map of 20 AER of NBSS & LUP (Gajbhiye and Mandal, 2006[3]). The information has been utilized for this purpose for Andhra Pradesh in Fig. 9. Major geographical area of the state lies in Deccan Plateau (*Telangana*) and Eastern Ghats, hot semi-arid eco-region followed by Eastern Plateau (Chhotanagpur) and Eastern Ghats, hot sub-humid eco-region. Further classification of this zonation into sub-regions is given in Fig. 10 which indicates that large areas of the state are climatically hot moist semi-arid in Northern *Telangana* Plateau.

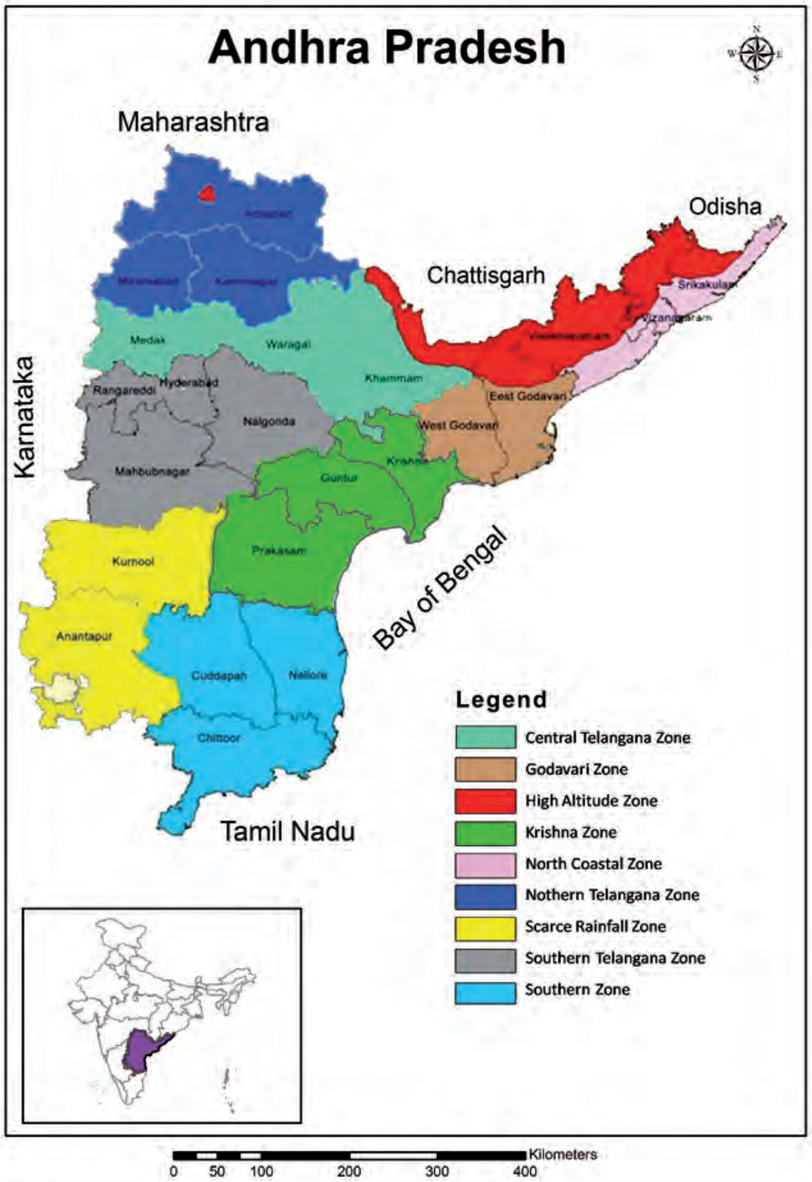


Fig. 8: Agro-climatic zones of Andhra Pradesh

(Source: Department of Agriculture, Government of Andhra Pradesh, 2011)

[3] Gajbhiye, K.S. and Mandal C. 2006. Agro-ecological zones, their soil resource and cropping systems. available at http://agricoop.nic.in/Farm%20Mech.%20PDF/05024-01.pdf

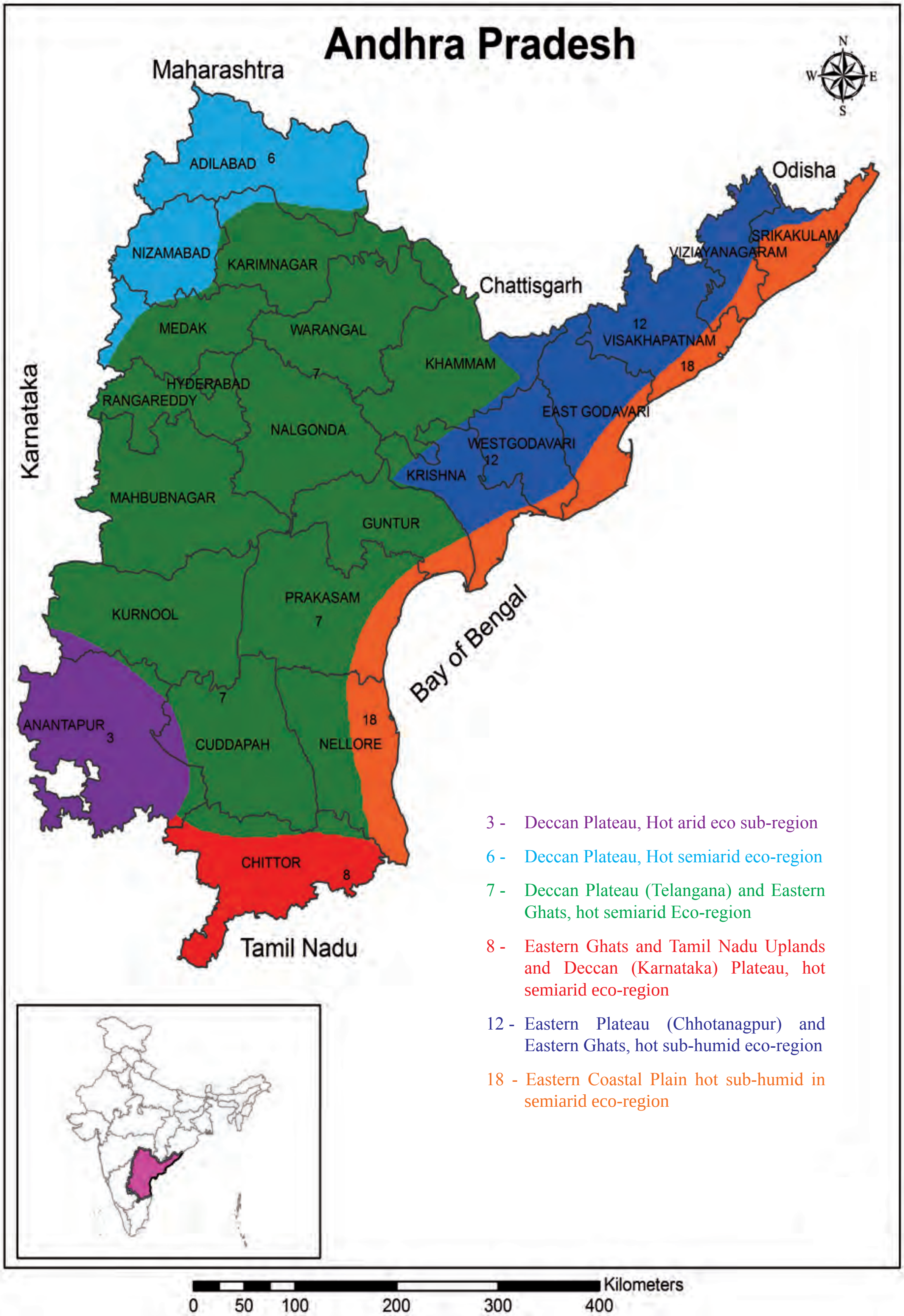


Fig. 9: Agro-ecological regions of Andhra Pradesh

(Source: NBSS & LUP)

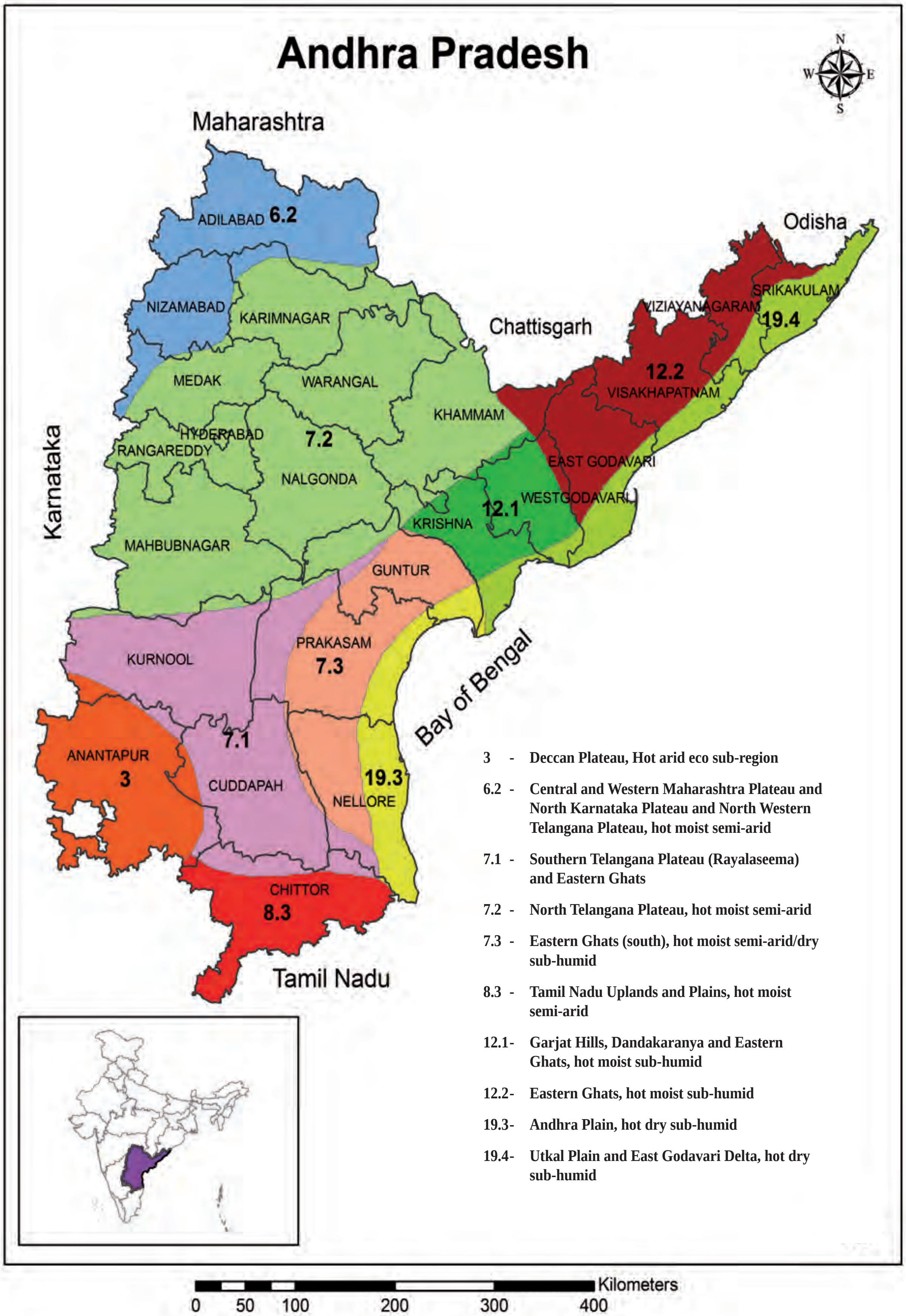


Fig. 10: Agro-ecological sub-regions of Andhra Pradesh

(Source: NBSS & LUP)

3. Agricultural scenario of Andhra Pradesh

As a background to better appreciate different aspects of climatological analysis information on agricultural scenario of Andhra Pradesh *viz.,* area, production and productivity in different regions and their trends are presented in this chapter. Productivity zones have been demarcated and production constrains *vis-a-vis* monsoon activity are briefly discussed. About 22 field crops are grown in the state and the area under some of these are noted to undergo wide inter-annual fluctuations for many reasons. Apart from the market demand, weather and socio-economic factors are some of the reasons leading to such fluctuations (in area under different crops). The trends in the area, production and productivity of 16 major crops (area >1,00,000 ha) have been analyzed and are presented hereunder:

3.1. Cereals

Paddy, maize and sorghum are the principal cereal crops of Andhra Pradesh. The area under paddy is about 35 lakh ha and there is a marginal increase in its area over the years (Fig. 11). The year to year fluctuations in area are mostly due to the drought / late release of canal waters. In 2002 and 2009, drought conditions in the state led to drastic reduction of the area under the crop. The paddy production has consistently increased @ 1.87 lakh tons per year. The paddy productivity has risen from 1359 kg ha^{-1} to 3344 kg ha^{-1} during the 27 year period from 1970 to 2007. Maize is the second largest grown cereal crop due to its commercial value (as poultry feed). The area under maize has risen from 2.56 lakh ha in 1970 to 7.86 lakh ha by 2008 covering non-conventional areas in Krishna-Godavari delta and in Medak district (Fig. 12). Productivity level of maize have increased from 1150 kg ha^{-1} in 1970s to 4025 kg ha^{-1} during 2005-07. However, in the case of sorghum, the area has decreased from 25 lakh ha in the 1970s to a meager 3 lakh ha during 2007-09 (Fig. 13). To an extent a steep increase in the productivity levels of the crop has come handy to commensurate the sharp decline in the area.

3.2. Pulses

The major pulse crops of the state are chickpea, pigeonpea, blackgram and greengram. Area under chickpea has picked up in recent years as a substitute for tobacco in Prakasam, Guntur and Kurnool districts. Introduction of high yielding cultivars has raised productivity of the crop from 429 kg ha^{-1} during 1980-90 to 1224 kg ha^{-1} during the period 2000-08 (Fig. 14).

Pigeonpea area has risen from 1.98 lakh ha during the period 1970-75 to 4.53 lakh ha 2005-09. This rise is partly due to introduction of pulses improvement program and partly to market forces (Fig. 15). Incidence of *Heliothis* (pod borer) during 1985-97 has reduced productivity of the crop to some extent. In other years, the inter-annual variability is largely weather driven.

Area, production and productivity of blackgram has varied over the years. Though there was a steep rise in all the three parameters during the second part of the 1980s, the crop was replaced by other remunerative crops mainly due to the occurrence of terminal moisture stress (in paddy fallows) and the incidence of YMV disease (Fig. 16). Area under green gram has showed a marginal decline in recent years but production levels have been sustained / enhanced due to an improvement in the productivity levels (Fig. 17).

3.3. Oilseeds

Groundnut is the principal oilseed crop of Andhra Pradesh. It is grown in 16.5 lakh ha. The area under this crop was at its peak during 1985-95 while it averaged 21.5 lakh ha (Fig. 18). The production and productivity trends of this crop have shown large variability over the years due to variation in the spread of rainfall. Anantapur district accounts for more than 50% of the total groundnut area of the state, and is the largest groundnut growing district.

Sunflower is the second largest oilseed crop grown in Andhra Pradesh. Its area, production and productivity have shown a sharp increase over the years (Fig. 19). There is a large inter-annual variability in the production of castor (Fig. 20). Its area and production have consistently declined. Similarly, area under sesame is also showing a sharp decline but with a marginal decrease in production. This may be due to the introduction of improved cultivars and production technology (Fig. 21). Among all the oilseed crops, castor is highly sensitive to excess moisture during its flowering and pod development stages. The receipt of pre-monsoon showers regulate area under the castor each year.

3.4. Commercial crops

Cotton is the principal commercial crop of the state. It is cultivated in more than 13 lakh ha. Though productivity trends of the crop show large variability there has been a constant increase in its area and production chiefly due to the introduction of Bt cotton, market forces and partly due to vagaries in the temporal distribution of monsoon rains. In years of early dry spells in the rainy season, more area is sown for cotton owing to its relative drought tolerance. The area earmarked to other crops which are moisture sensitive, are brought under cotton (Fig. 22). Apart from the spatial and temporal distribution of rainfall, insect pest damage is another important parameter that affects cotton productivity in AP. Incidence of white fly in 1985-87 and later *Heliothis* menace can be best cited examples. Chillies is another important commercial crop grown in over 2 lakh ha. The production and productivity of this crop has steeply increased over the years, though its area has hovered around 2 lakh ha. The productivity levels have risen from 6.6 q ha^{-1} in 1970 to 35.3 q ha^{-1} by 2008. This phenomenal rise could be attributed to the cultivation of HYV's on an extensive scale; large scale adoption of technology, and market linkages (Fig. 23). A gradual increase in sugarcane production has come through with a concurrent increase in the area over the years (Fig. 24). Large inter-annual variation in the productivity of the crop may be attributed primarily to the role played by weather, since large area under sugarcane crop is rainfed.

3.5. Delineation of production zones

The net sown area in the state has been classified / demarcated into different categories of production zones of the widely grown crops during 2007-09. The criteria adapted for the categorization is the area under each crop and those districts contributing above 50% of the area in the state are termed as primary zone and districts contributing 35% of net area sown under the crop in consideration are classified as secondary and the rest of the districts as tertiary zones. Marginal area (< 1000 ha) in each district is put under the marginal category. The zones classified crop wise are shown in Table 4 and presented in Fig. 25 to 40. This type of categorization helps in planning and implementing projects to expand areas under the crops currently grown or to introduce new crops or their cultivars into the new area.

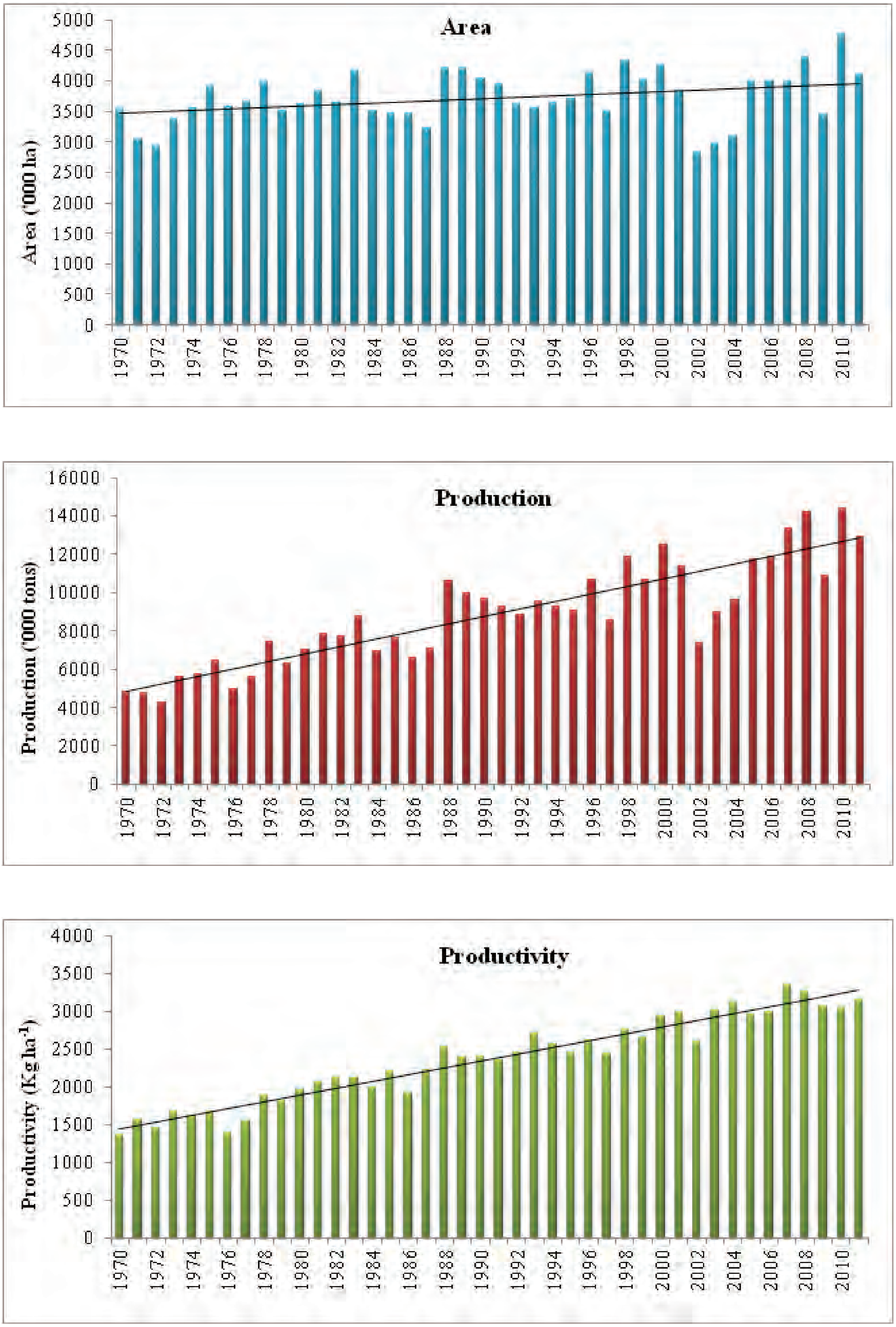


Fig. 11: Trends in area, production and productivity of paddy in Andhra Pradesh (1970-2011)

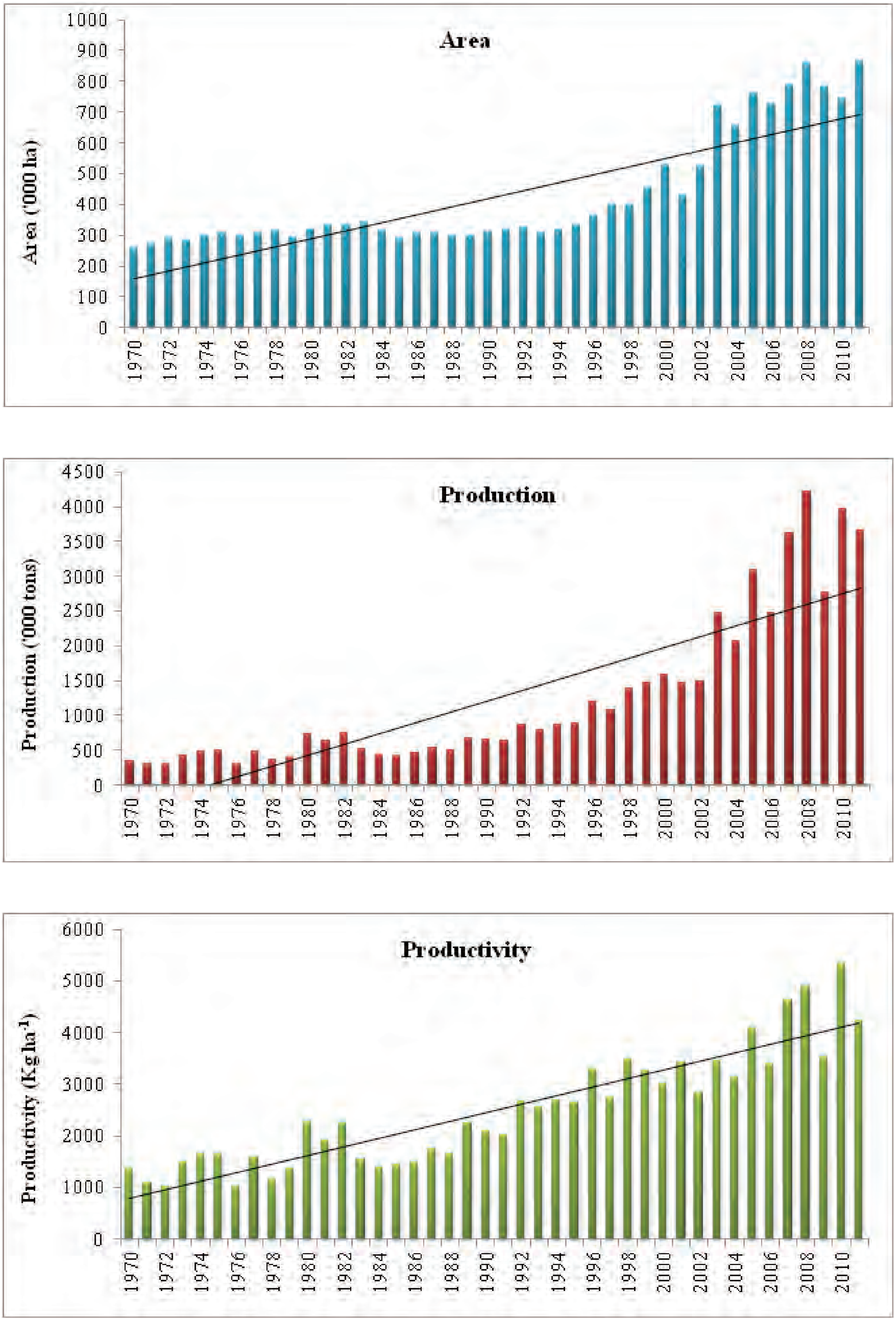
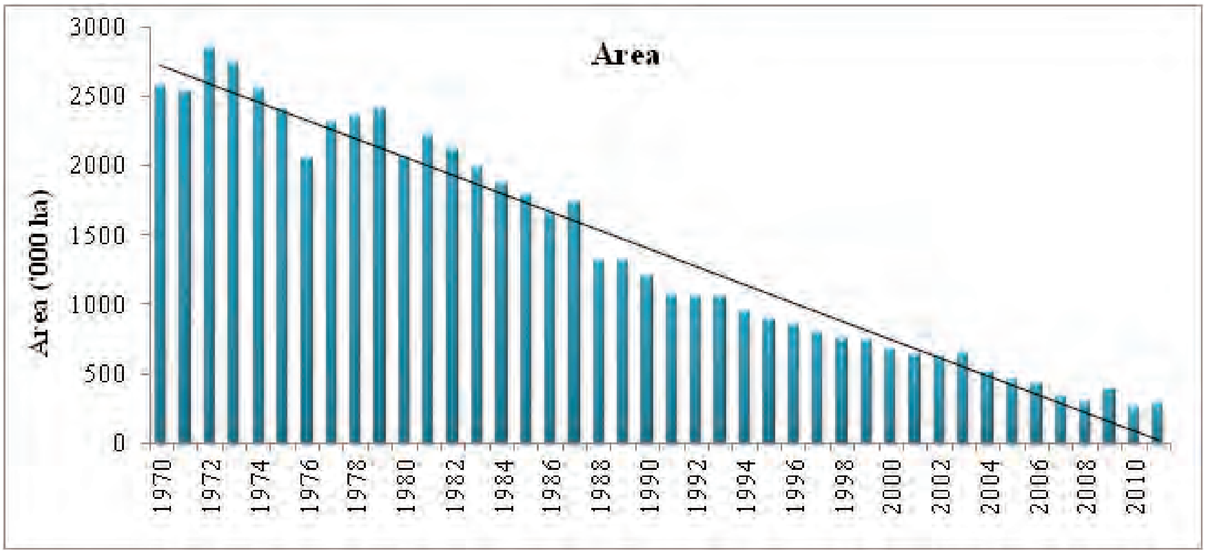


Fig. 12: Trends in area, production and productivity of maize in Andhra Pradesh (1970-2011)



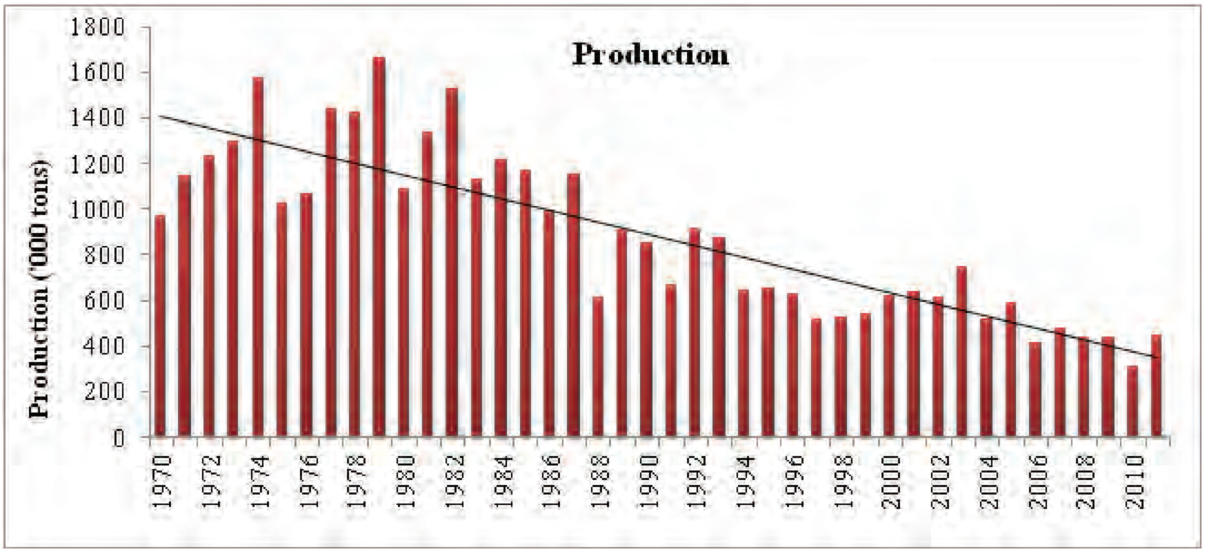


Fig. 13: Trends in area, production and productivity of sorghum in Andhra Pradesh (1970-2011)

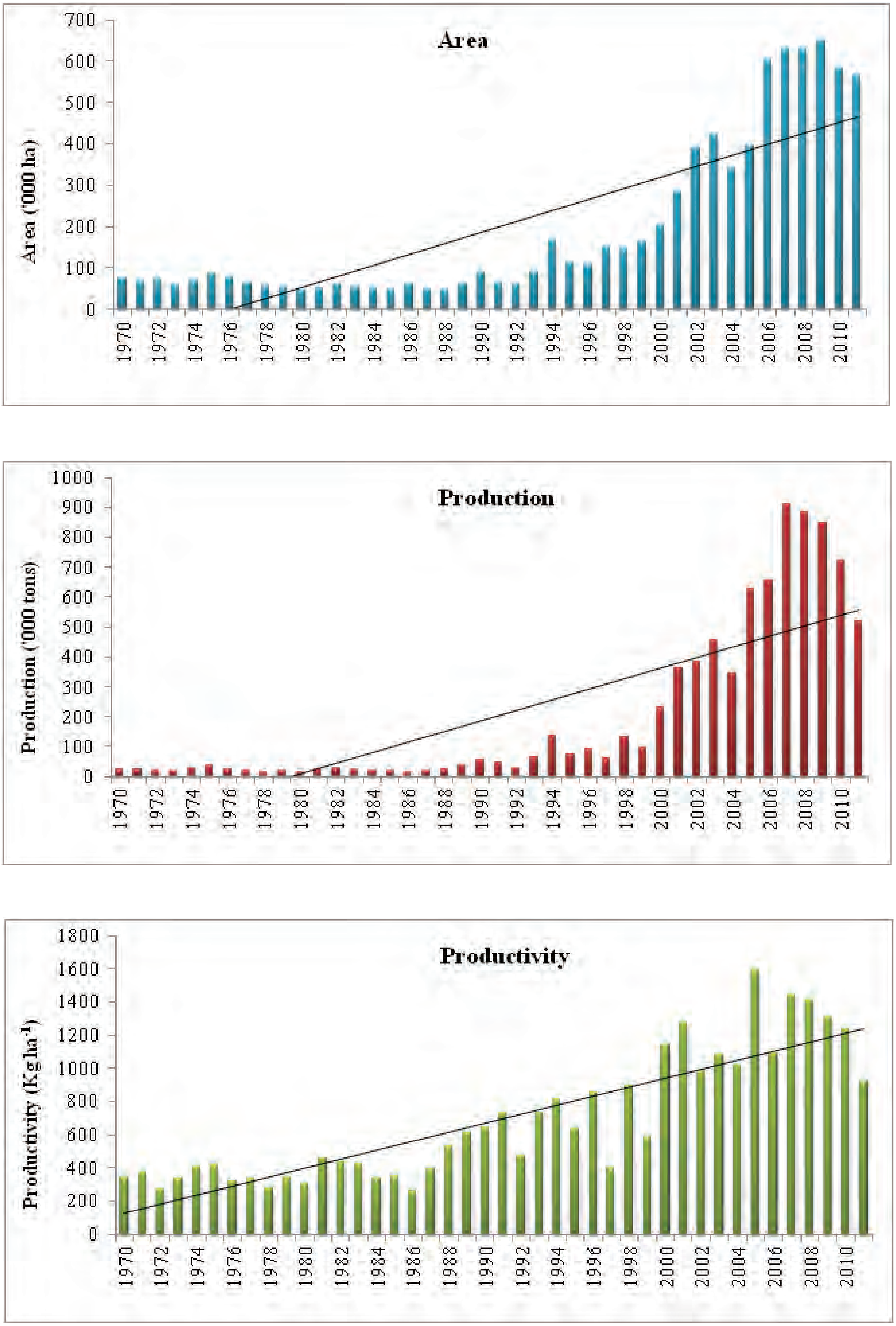


Fig. 14: Trends in area, production and productivity of chickpea in Andhra Pradesh (1970-2011)

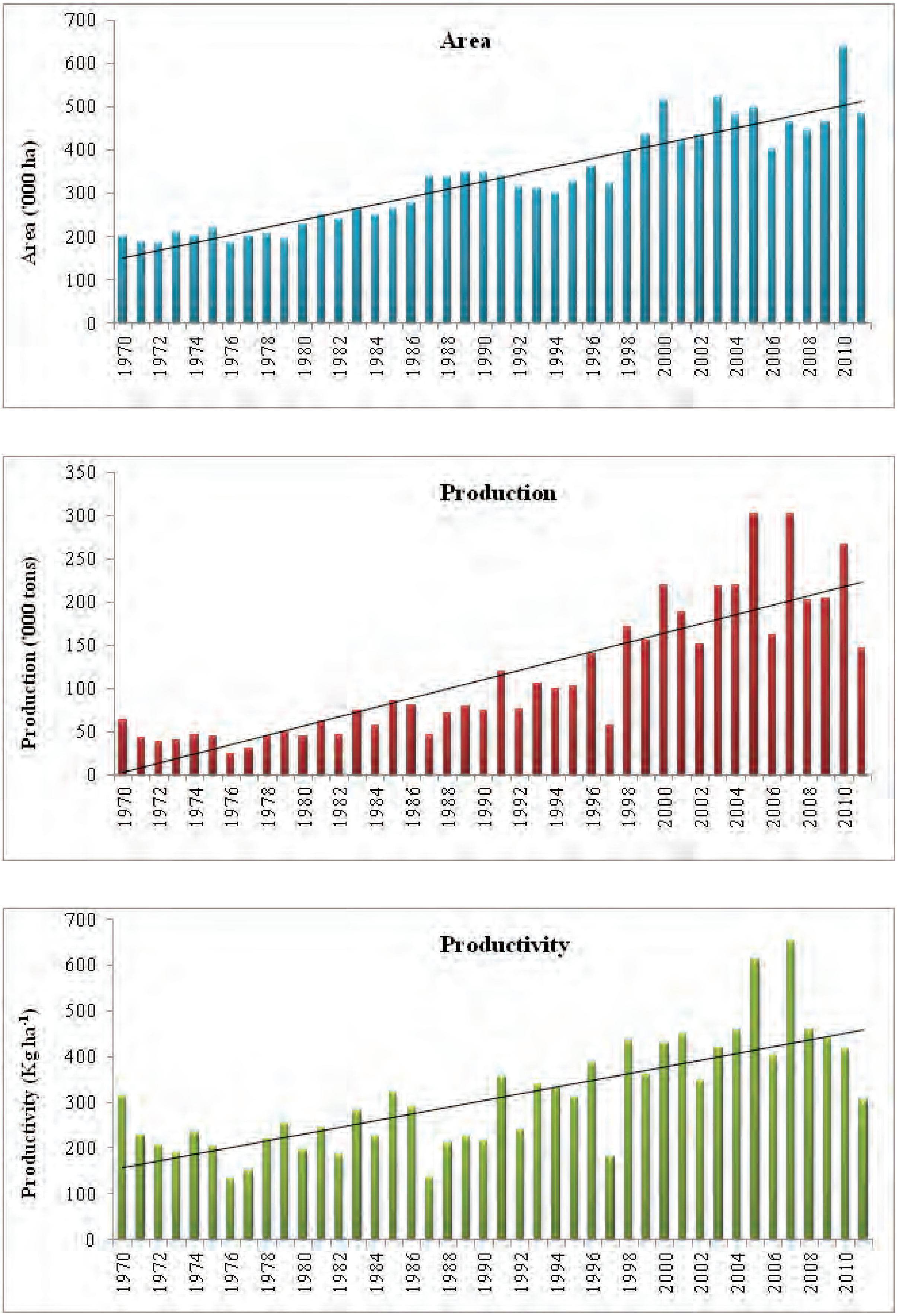


Fig. 15: Trends in area, production and productivity of pigeonpea in Andhra Pradesh (1970-2011)

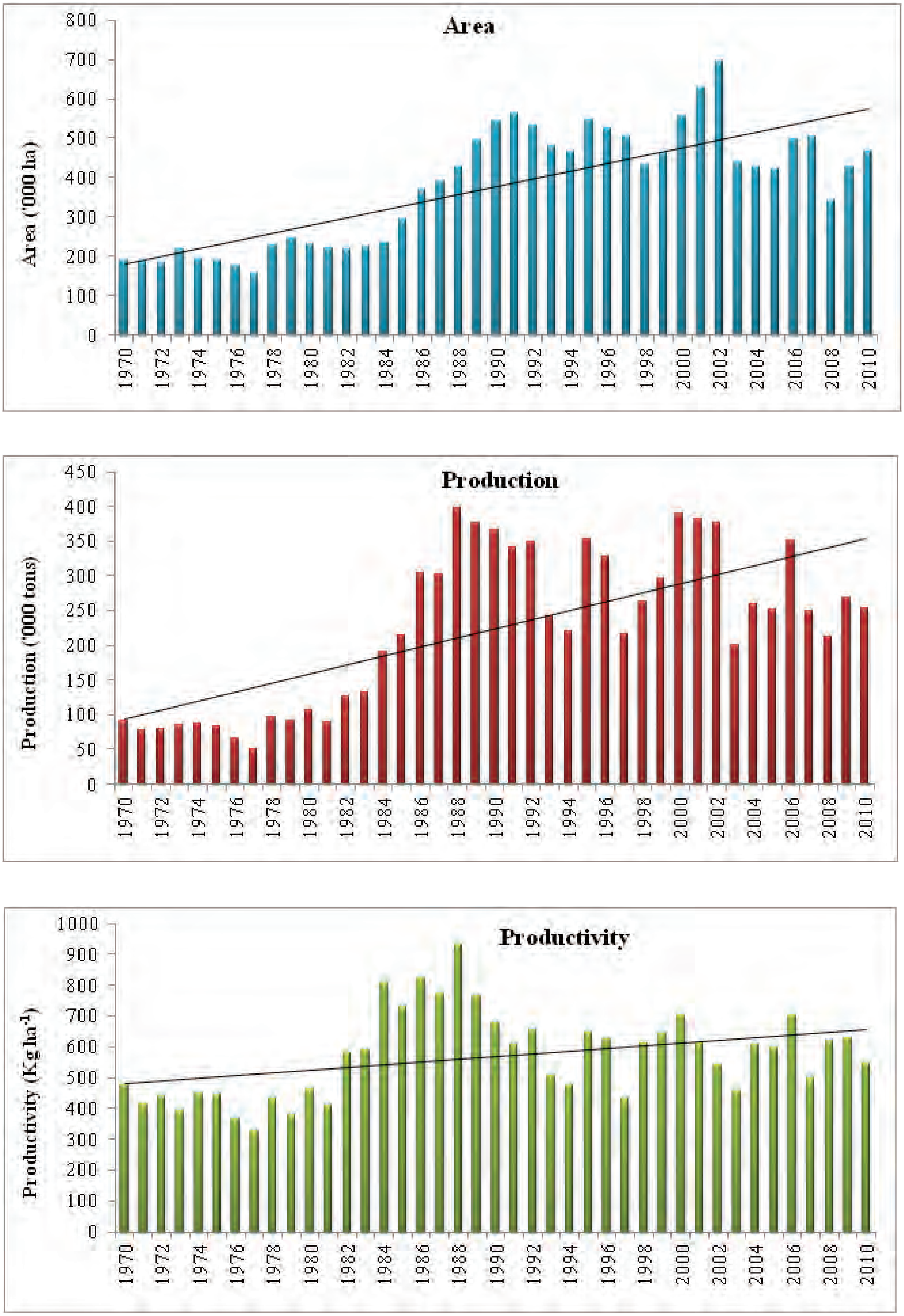


Fig. 16: Trends in area, production and productivity of blackgram in Andhra Pradesh (1970-2010)

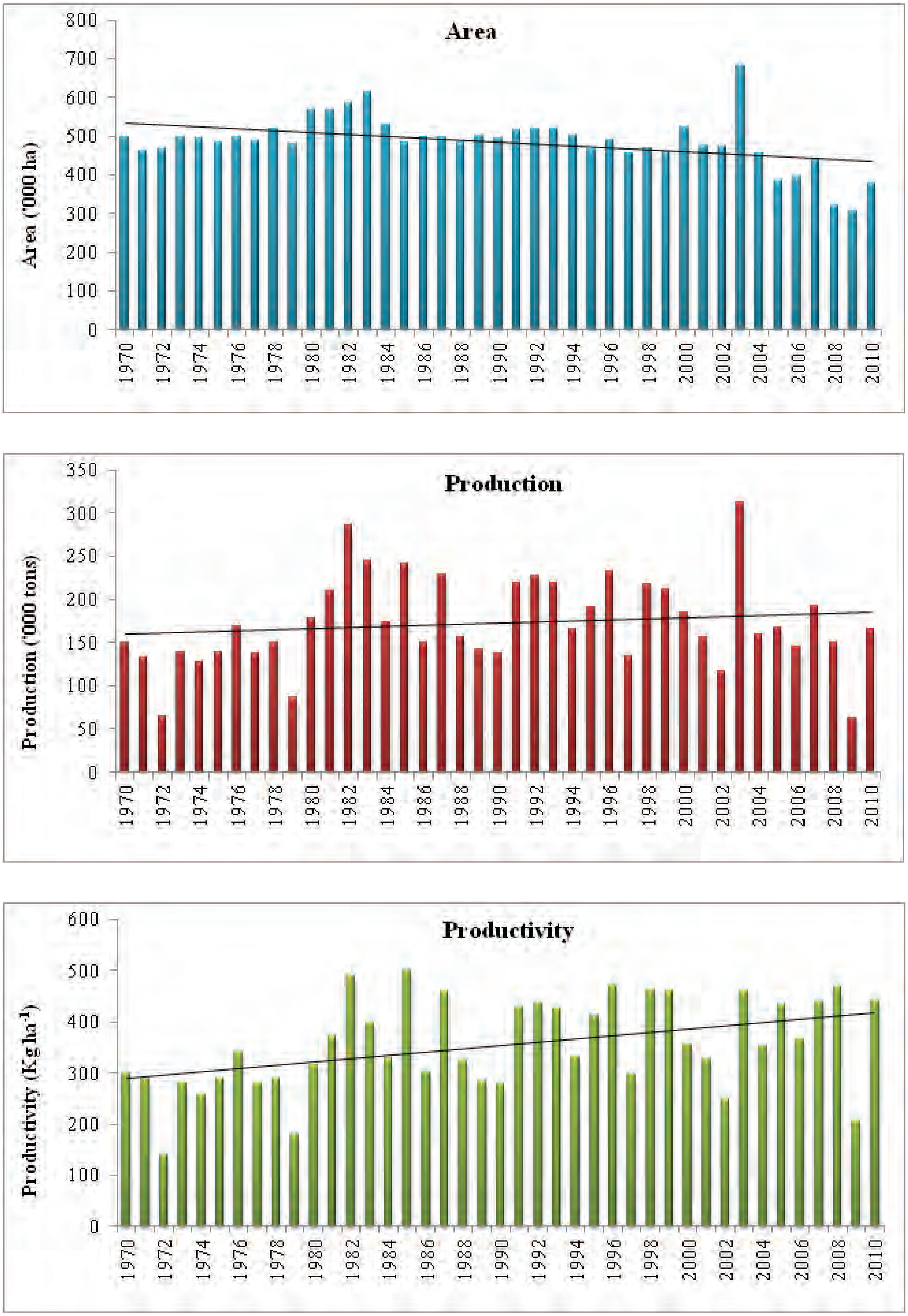


Fig. 17: Trends in area, production and productivity of greengram in Andhra Pradesh (1970-2010)

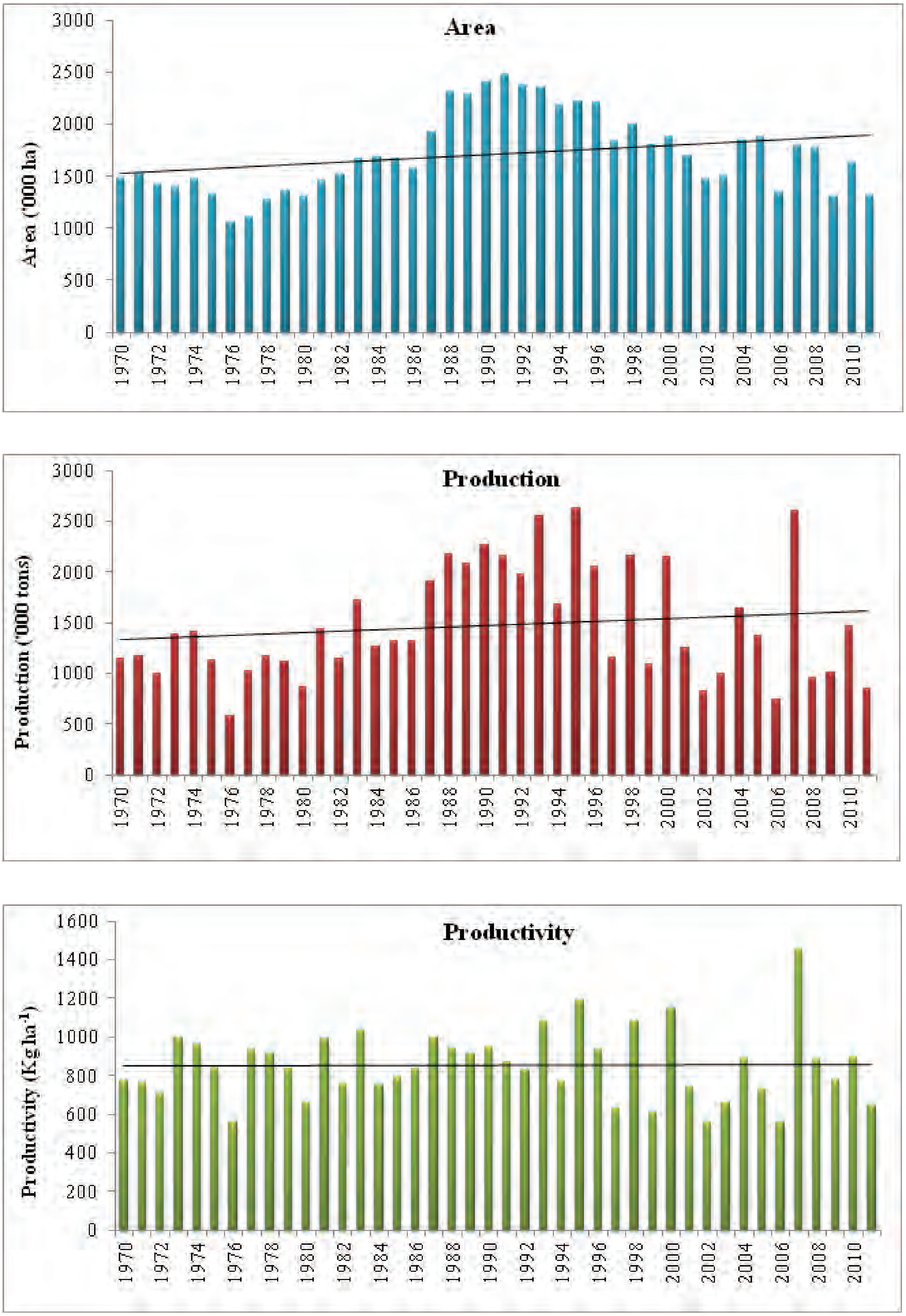


Fig. 18: Trends in area, production and productivity of groundnut in Andhra Pradesh (1970-2011)

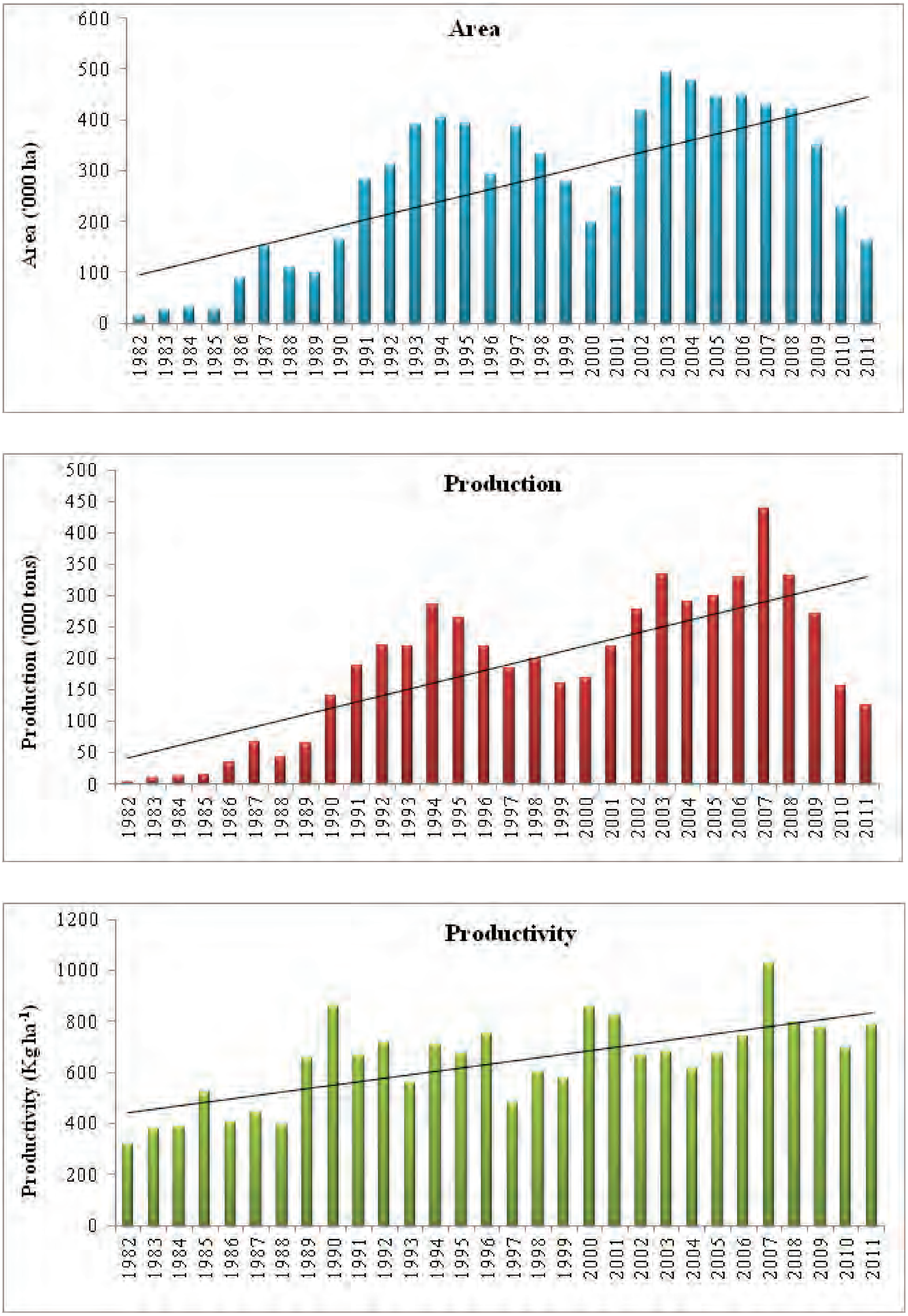


Fig. 19: Trends in area, production and productivity of sunflower in Andhra Pradesh (1982-2011)

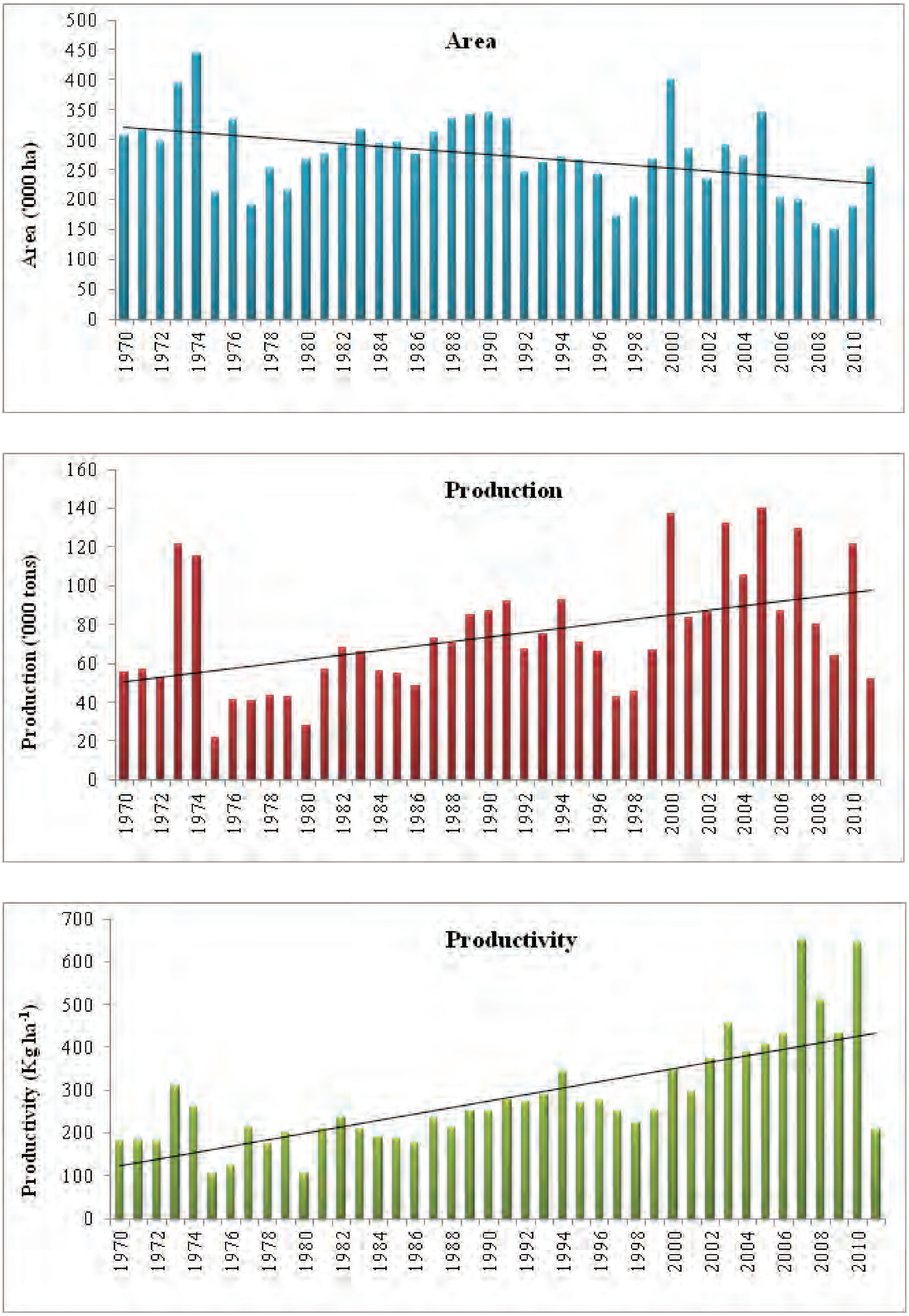
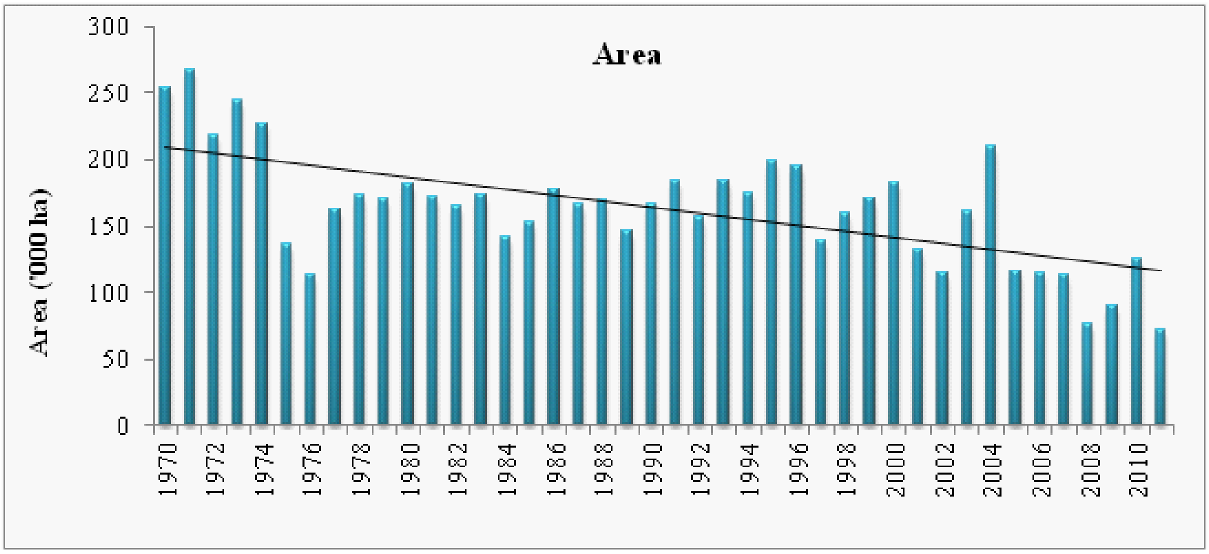
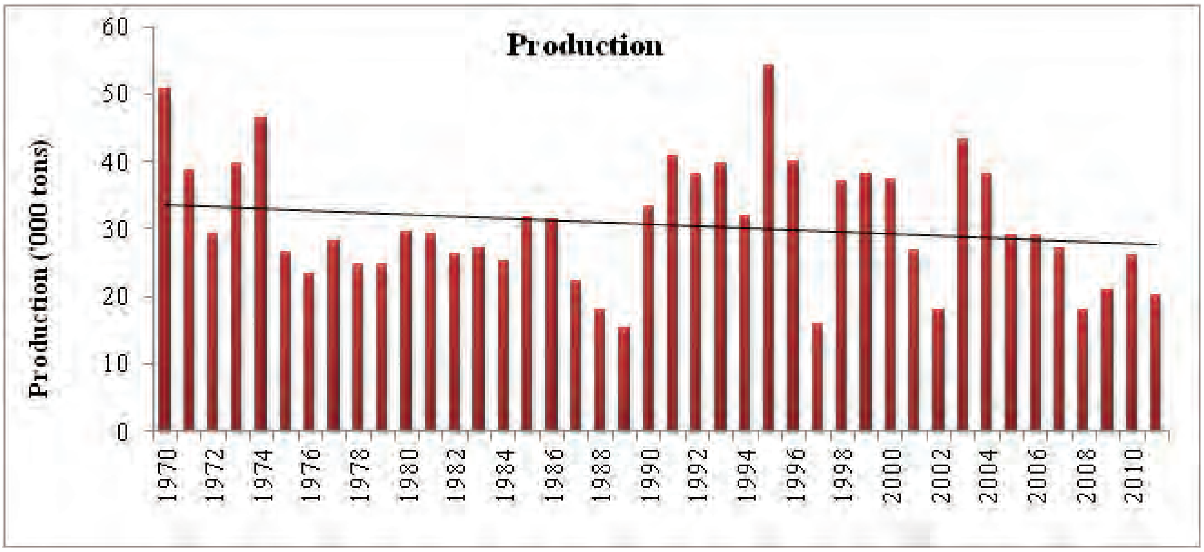


Fig. 20: Trends in area, production and productivity of castor in Andhra Pradesh (1970-2011)





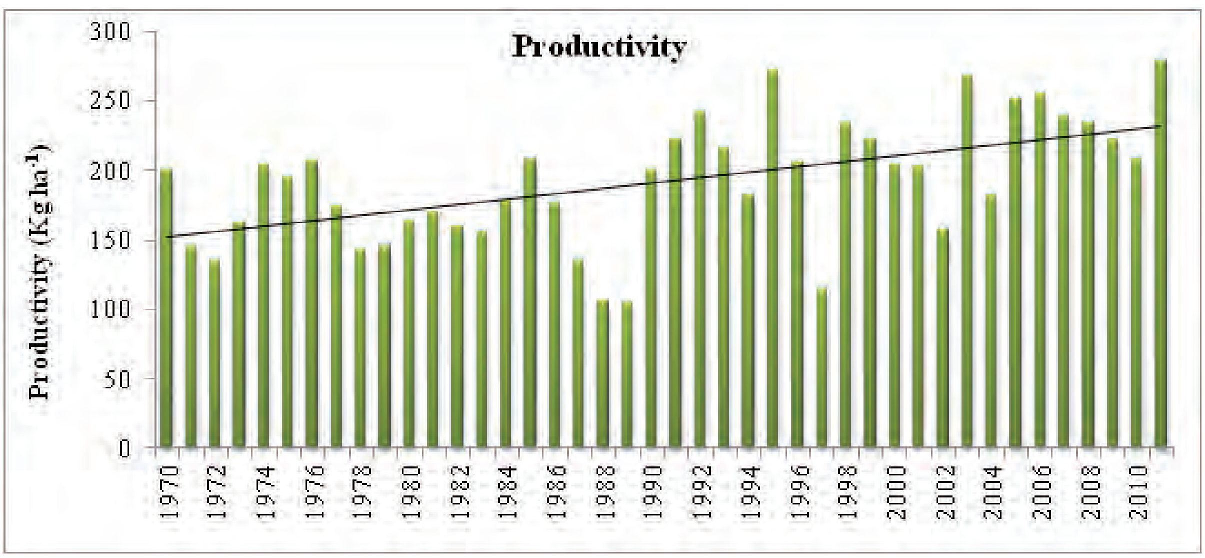
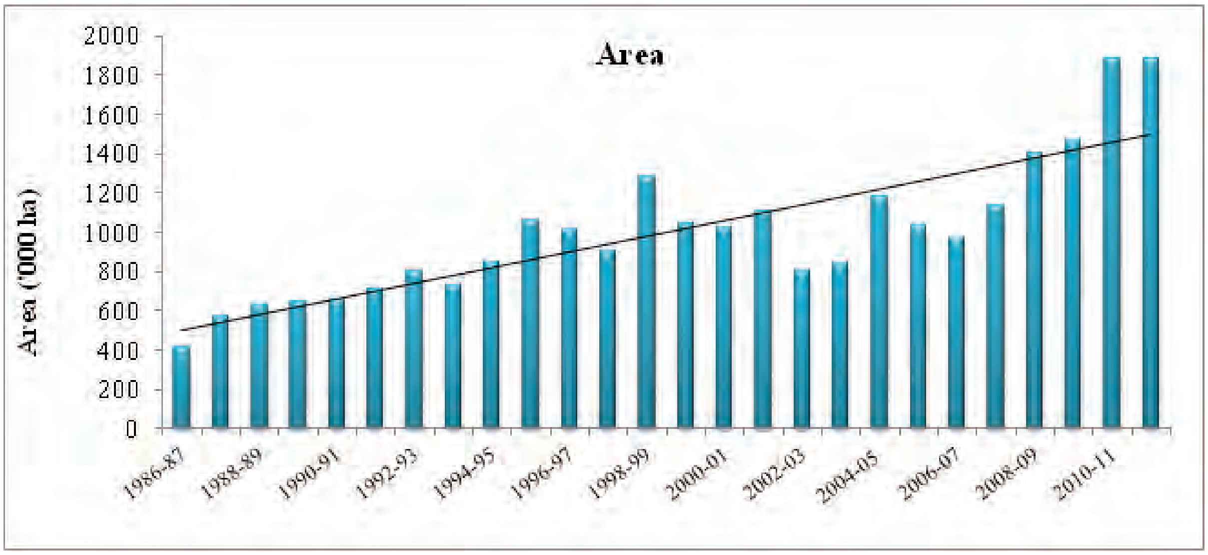
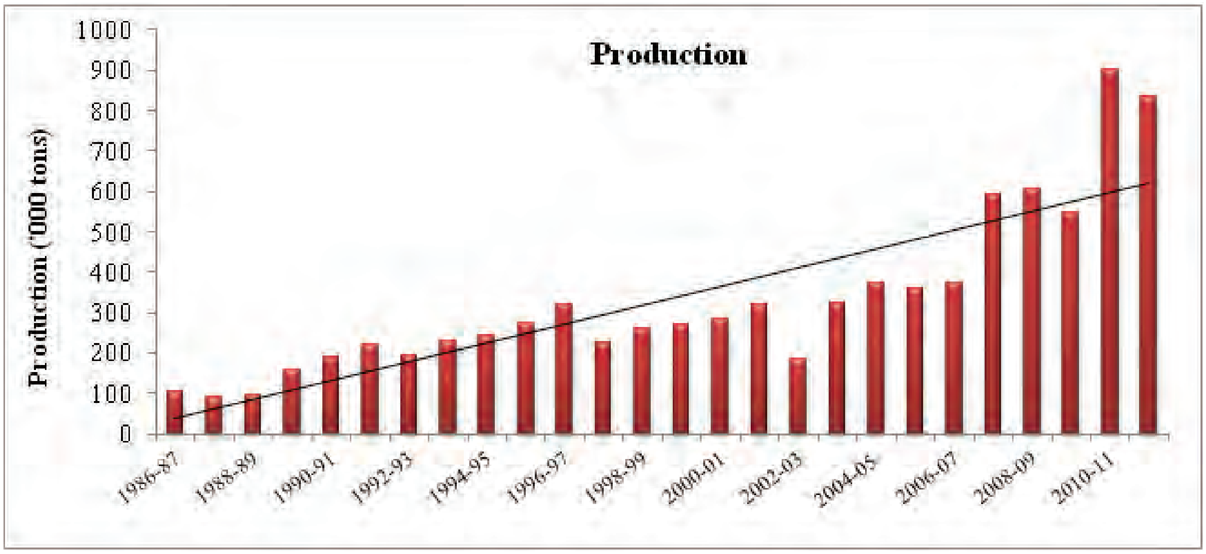


Fig. 21: Trends in area, production and productivity of sesame in Andhra Pradesh (1970-2011)





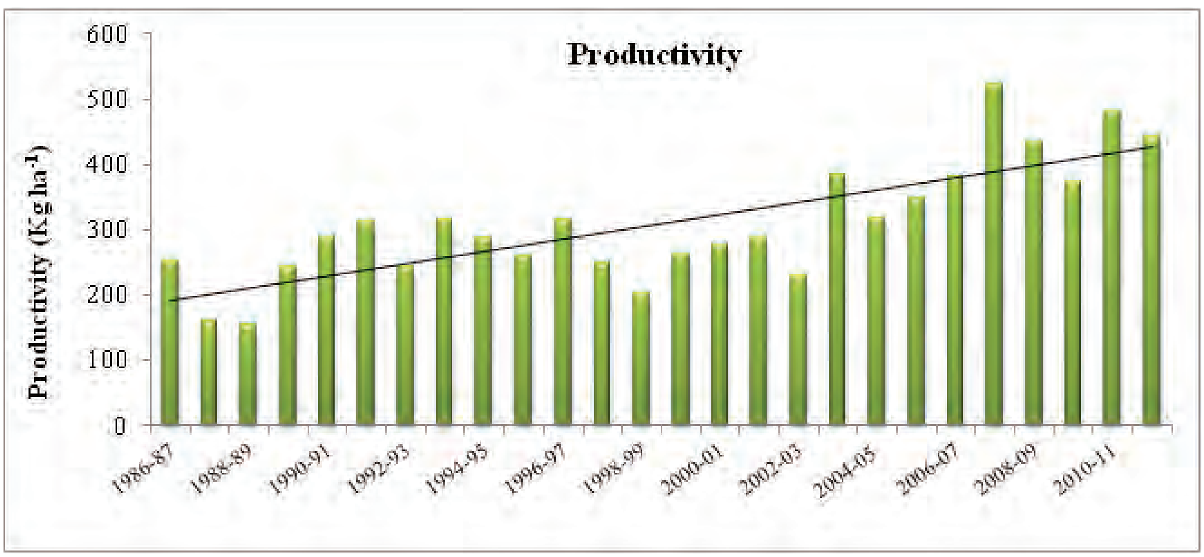


Fig. 22: Trends in area, production and productivity of cotton in Andhra Pradesh (1986-87 to 2011-12)

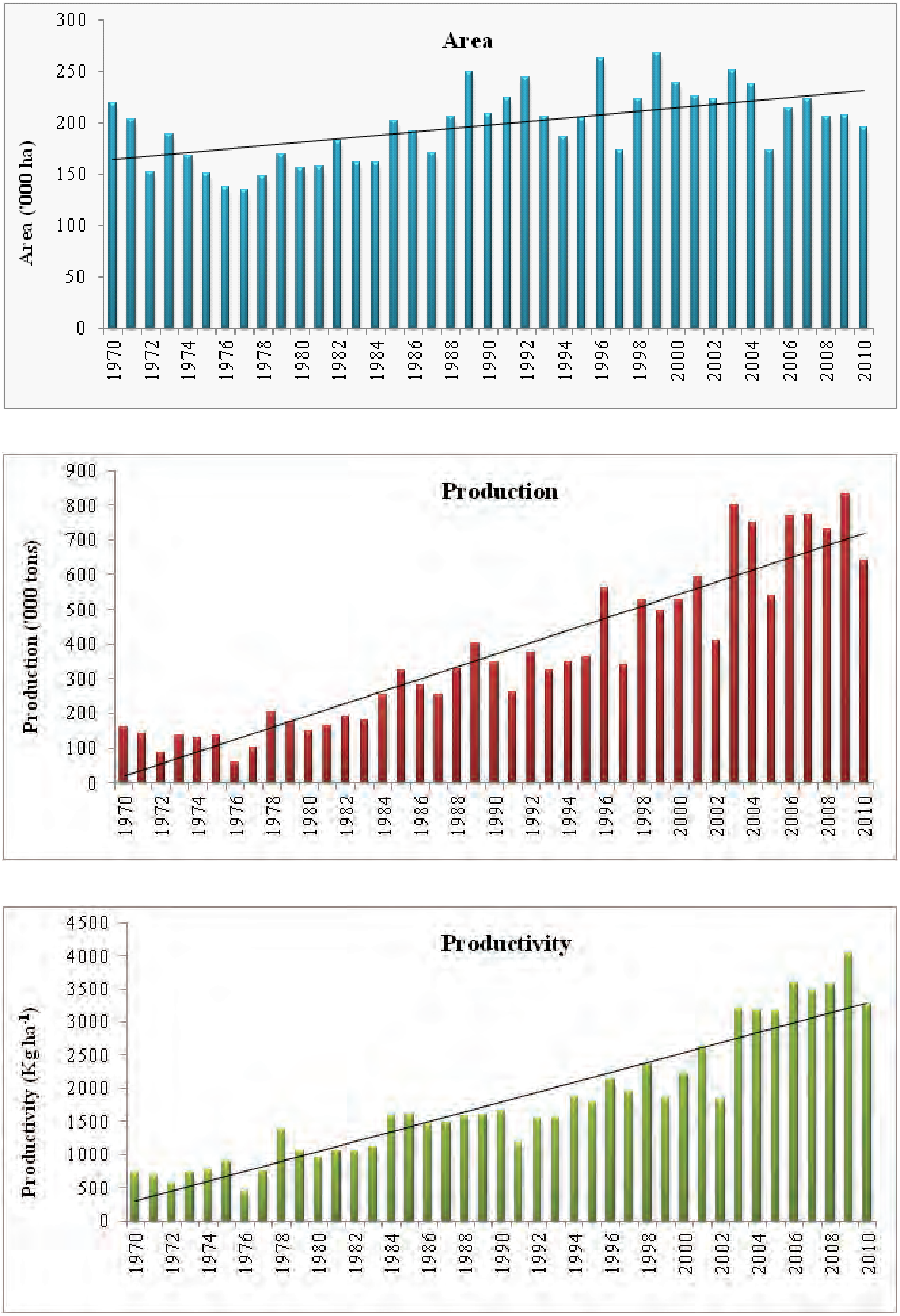


Fig. 23: Trends in area, production and productivity of chilies in Andhra Pradesh (1970-2010)

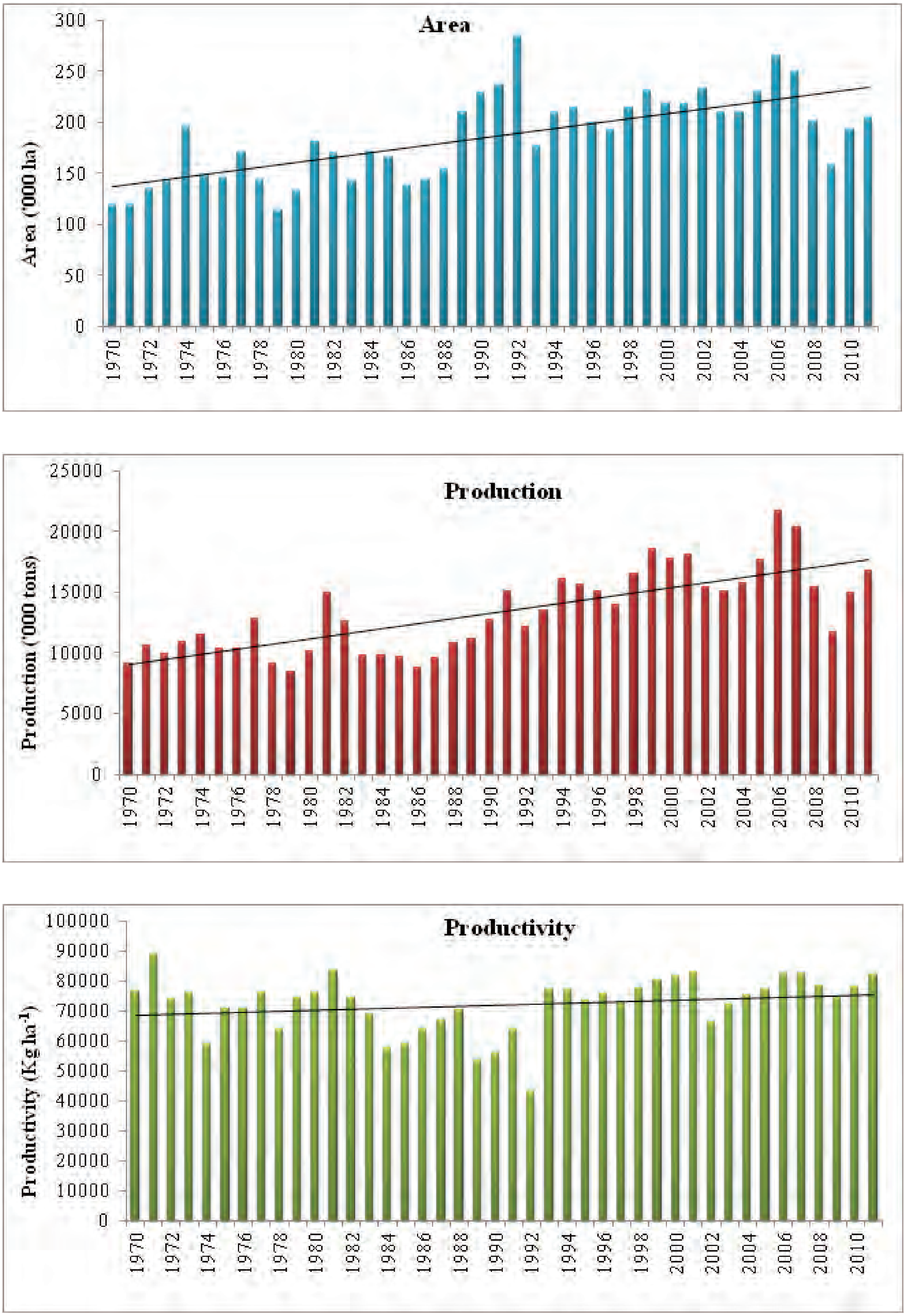


Fig. 24: Trends in area, production and productivity of sugarcane in Andhra Pradesh (1970-2011)

Table 4: Delineation of net sown area into different production zones of principal crops of Andhra Pradesh

Crops	Primary zone		Secondary zone		Tertiary zone		Others	
	Districts	Area (ha)	Districts	Area (ha)	Districts	Area (ha)	Districts	Area (ha)
Paddy	West Godavari, East Godavari, Krishna, Nalgonda, Guntur, Karimnagar	20,36,038	SPSR Nellore, Srikakulam, Warangal, Khammam, Mahabubnagar, Nizamabad, Prakasam, Vizianagaram	13,37,378	Kurnool, Medak, Visakhapatnam, YSR Kadapa, Adilabad, Chittoor, Anantapur, Ranga Reddy	5,63,901		
Maize	Karimnagar, Mahabubnagar, Medak, Warangal	4,32,450	Guntur, Nizamabad, West Godavari, Khammam, Ranga Reddy	2,49,515	Adilabad, Krishna, Kurnool, Vizianagarm, Anantapur, East Godavari, Visakhapatnam, Prakasam, Srikakulam, Nalgonda, Chittoor, YSR Kadapa	1,24,453	SPSR Nellore	551
Sorghum	Kurnool, Mahabubnagar, Adilabad	1,81,053	Medak, Anantapur, Ranga Reddy, Nalgonda	1,05,967	Nizamabad, YSR Kadapa, Warangal, Prakasam, Khammam, Guntur, Krishna, Chittoor, Karimnagar, Visakhapatnam	43,738	East Godavari, Vizianagaram, West Godavari, Srikakulam SPSR Nellore	2,056
Chickpea	Kurnool, Prakasam	3,30,877	Anantapur, YSR Kadapa, Medak, Nizamabad	2,19,075	Mahabubnagar, Adilabad, Guntur, SPSR Nellore, Ranga Reddy, Karimnagar, Warangal	74,904	Krishna, Nalgonda, East Godavari, Vizianagaram, Khammam, West Godavari, Visakhapatnam, Chittoor	3,053
Red gram	Mahabubnagar, Prakasam, Adilabad, Nalgonda	2,30,304	Ranga Reddy, Kurnool, Anantapur, Medak, Guntur, Warangal	1,67,602	Khammam, YSR Kadapa, Karimnagar, Chittoor, Krishna, Nizamabad, Visakhapatnam, Vizianagaram, Srikakulam, SPSR Nellore, East Godavari	58,151	West Godavari	551

Crops	Primary zone		Secondary zone		Tertiary zone		Others	
	Districts	Area (ha)	Districts	Area (ha)	Districts	Area (ha)	Districts	Area (ha)
Black gram	Krishna, Guntur, Srikakulam	2,26,666	East Godavari, SPSR Nellore Medak, Vizianagaram, Nizamabad, Adilabad	1,34,768	West Godavari, Prakasam, Khammam Ranga Reddy, Kurnool Visakhapatnam, Mahabubnagar, Warangal, Nalgonda	61,180	Chittoor, Karimnagar, YSR Kadapa, Anantapur	1,516
Green gram	Medak, East Godavari, Srikakulam, Nalgonda, Mahabubnagar	1,87,442	Warangal, Khammam, Nizamabad, Vizianagaram, Adilabad, Karimnagar	1,11,765	Krishna, Prakasam, Ranga Reddy, Visakhapatnam, Guntur, Kurnool, West Godavari, SPSR Nellore	53,929	Chittoor, Anantapur, YSR Kadapa	1,737
Ground nut	Anantapur	7,65,946	Kurnool, Chittoor, YSR Kadapa, Mahabubnagar	6,43,636	Warangal, Vizianagaram, Srikakulam, Nalgonda, Karimnagar, SPSR Nellore, Prakasam, West Godavari, Krishna, Ranga Reddy, Khammam, Guntur, Adilabad, Visakhapatnam, Nizamabad, Medak	2,10,912	East Godavari	528
Sunflower	Kurnool, YSR Kadapa	2,18,440	Anantapur, Prakasam, Nizamabad, Mahabubnagar	1,34,043	Medak, SPSR Nellore, Adilabad, Chittoor, Srikakulam, West Godavari, Nalgonda, Karimnagar	43,471	East Godavari, Ranga Reddy, Visakhapatnam, Khammam, Warangal, Krishna, Guntur, Vizianagarm	3,066

Crops	Primary zone		Secondary zone		Tertiary zone		Others	
	Districts	Area (ha)	Districts	Area (ha)	Districts	Area (ha)	Districts	Area (ha)
Castor	Mahabubnagar	96,840	Nalgonda, Kurnool	46,821	Prakasam, Ranga Reddy, Warangal, Guntur, Anantapur, Medak, YSR Kadapa	23,475	Karimnagar, Chittoor, Adilabad, Nizamabad, East Godavari, SPSR Nellore, Khammam, Visakhapatnam, Vizianagaram	1,647
Sesame	Vizianagaram, Prakasam, Warangal, Srikakulam	52,293	Visakhapatnam, YSR Kadapa, Adilabad, Khammam, Nalgonda, Karimnagar	29,329	SPSR Nellore, Nizamabad, East Godavari, Guntur, West Godavari	9,441	Medak, Ranga Reddy, Mahabubnagar, Kurnool, Chittoor, Krishna	4,186
Cotton	Adilabad, Warangal, Karimnagar, Guntur	7,59,036	Nalgonda, Khammam, Mahabubnagar, Medak	4,00,830	Krishna, Prakasam, Kurnool, Ranga Reddy, Nizamabad, YSR Kadapa, Vizianagaram, East Godavari, SPSR Nellore, West Godavari, Anantapur, Srikakulam	1,73,112	Visakhapatnam, Chittoor	614
Chillies	Guntur, Khammam, Warangal	1,18,472	Prakasam, Kurnool, Krishna, Mahabubnagar, Nalgonda, Karimnagar	61,928	Adilabad, Medak, Srikakulam, Chittoor, West Godavari, Nizamabad, Visakhapatnam, SPSR Nellore, Vizianagaram, Anantapur, YSR Kadapa, Ranga Reddy, East Godavari	30,567		
Sugar cane	Visakhapatnam, West Godavari, Chittoor	96,289	Medak, Vizianagaram, East Godavari, Krishna, Nizamabad	79,960	SPSR Nellore, Srikakulam, Khammam, Karimnagar, Kurnool, Ranga Reddy, Guntur	23,276	YSR Kadapa, Nalgonda, Adilabad, Anantapur, Prakasam, Mahabubnagar	1,490

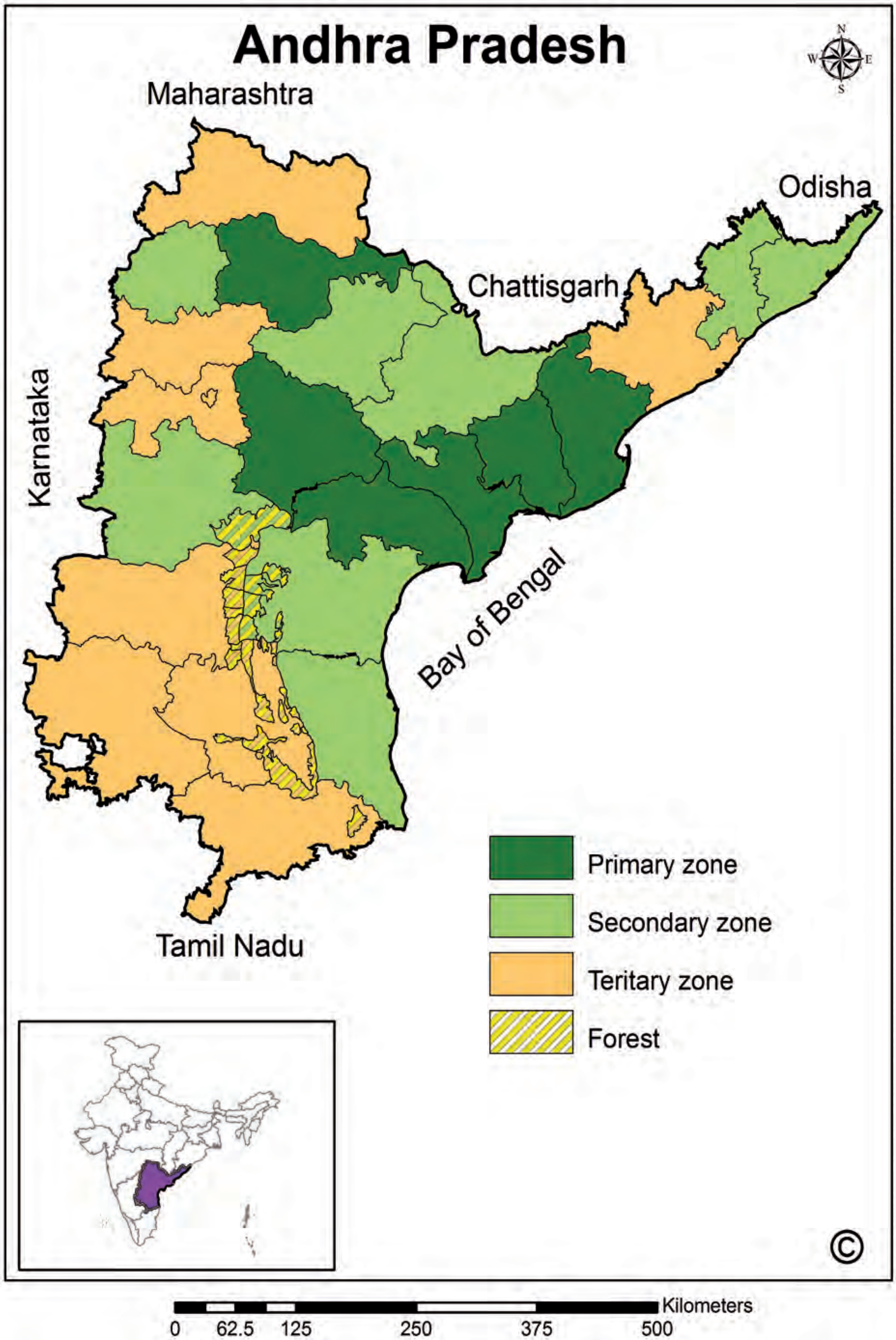


Fig. 25: Production zones of paddy in Andhra Pradesh

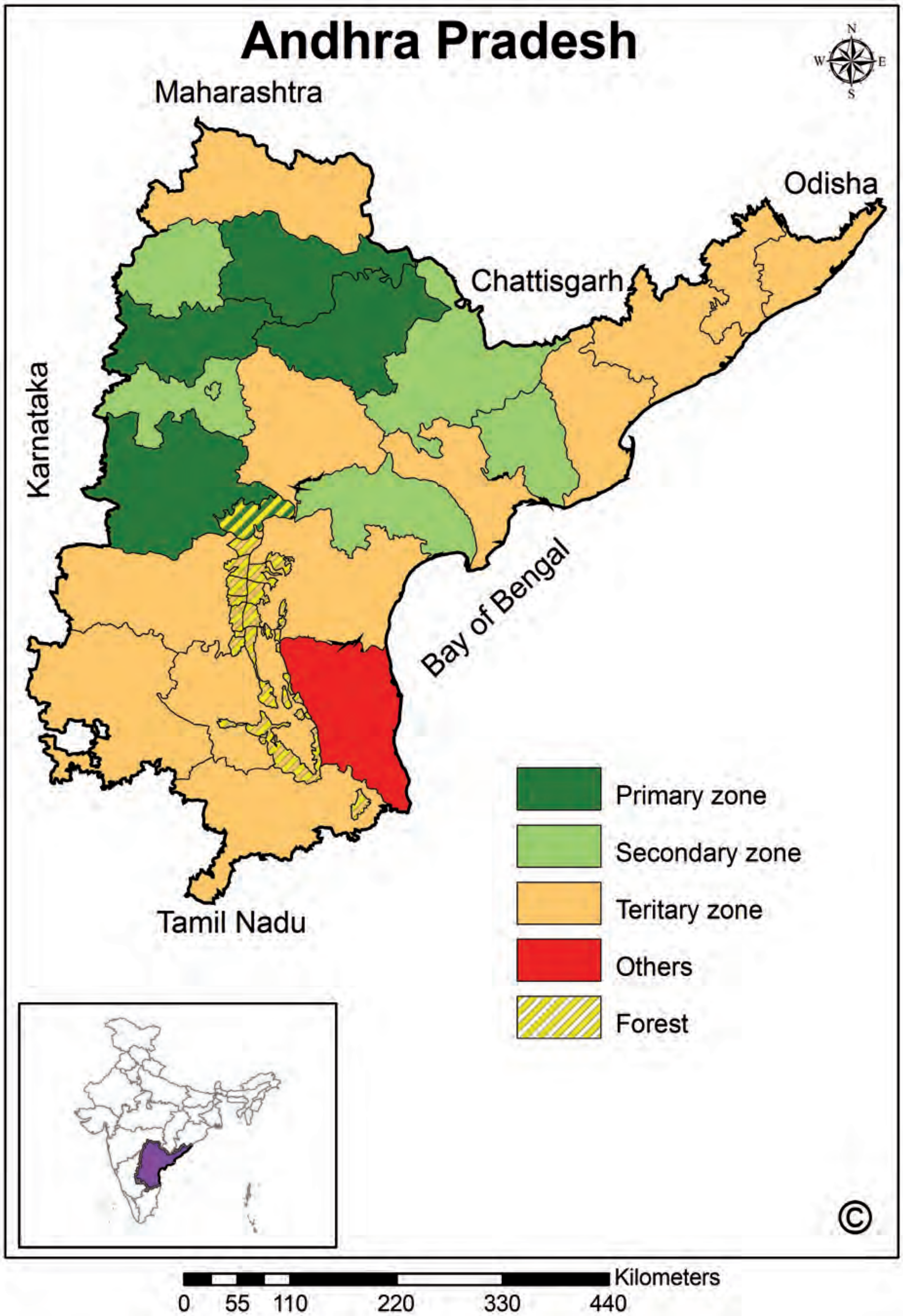


Fig. 26: Production zones of maize in Andhra Pradesh

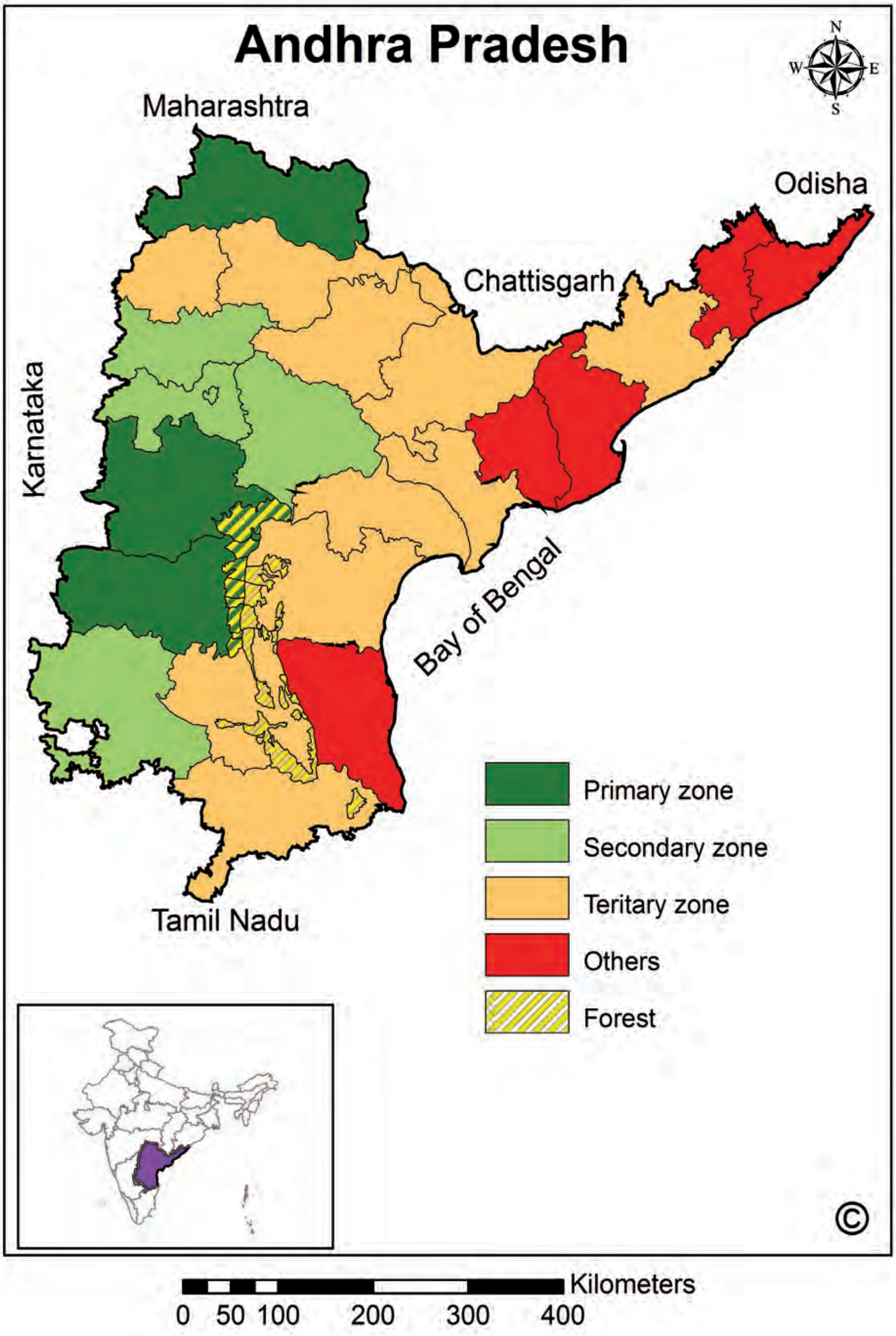


Fig. 27: Production zones of sorghum in Andhra Pradesh

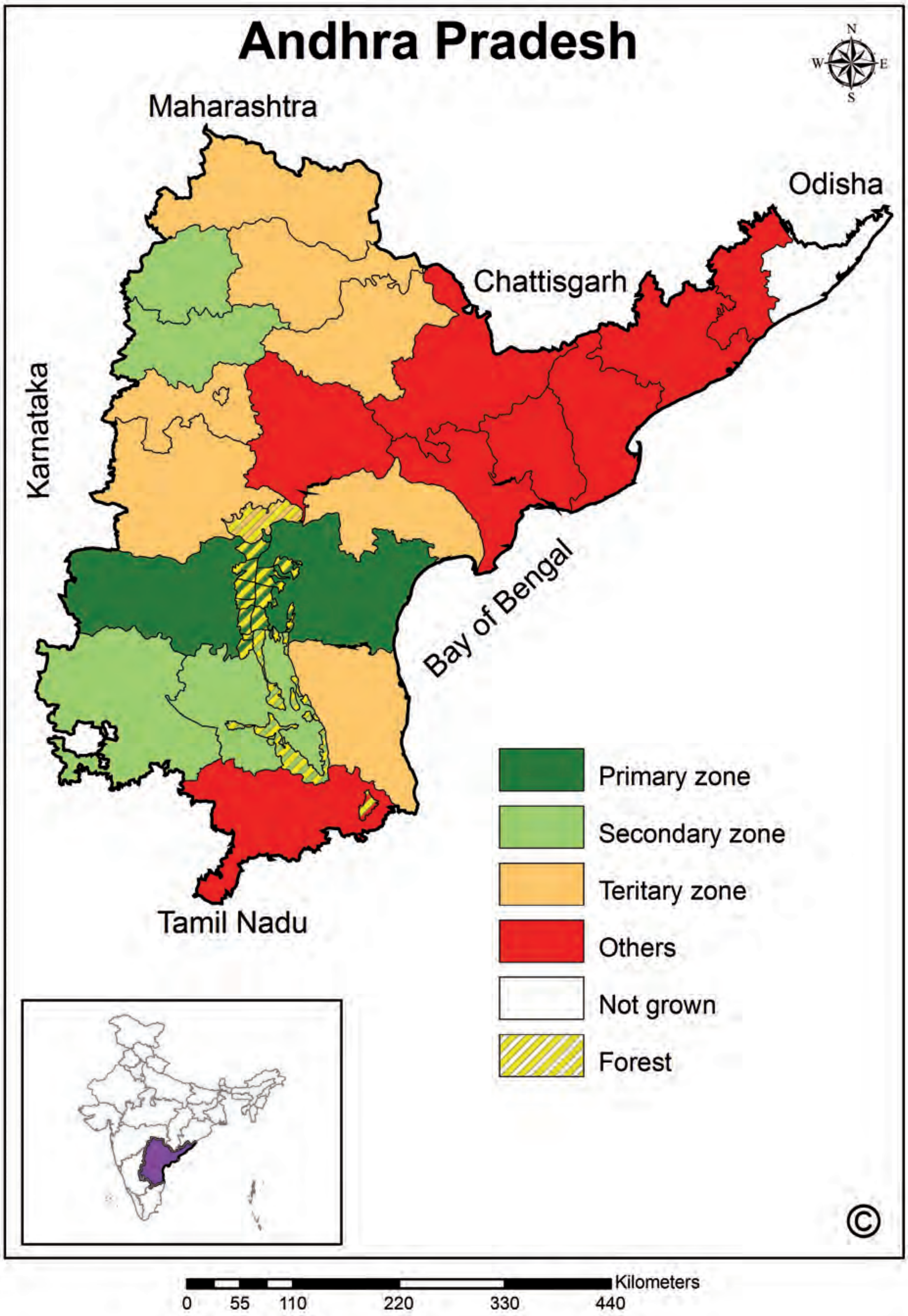


Fig. 28: Production zones of chickpea in Andhra Pradesh

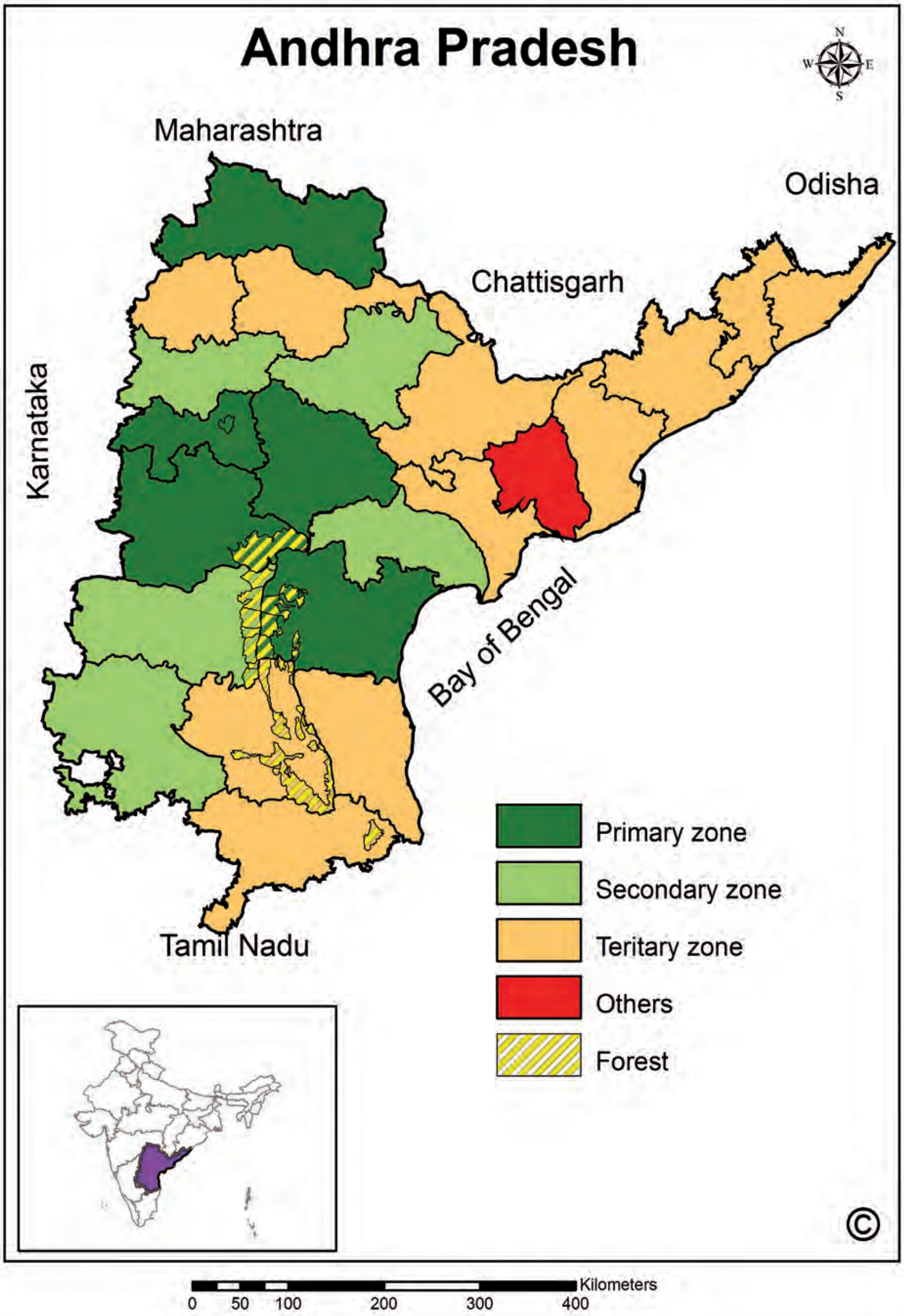


Fig. 29: Production zones of pigeonpea in Andhra Pradesh

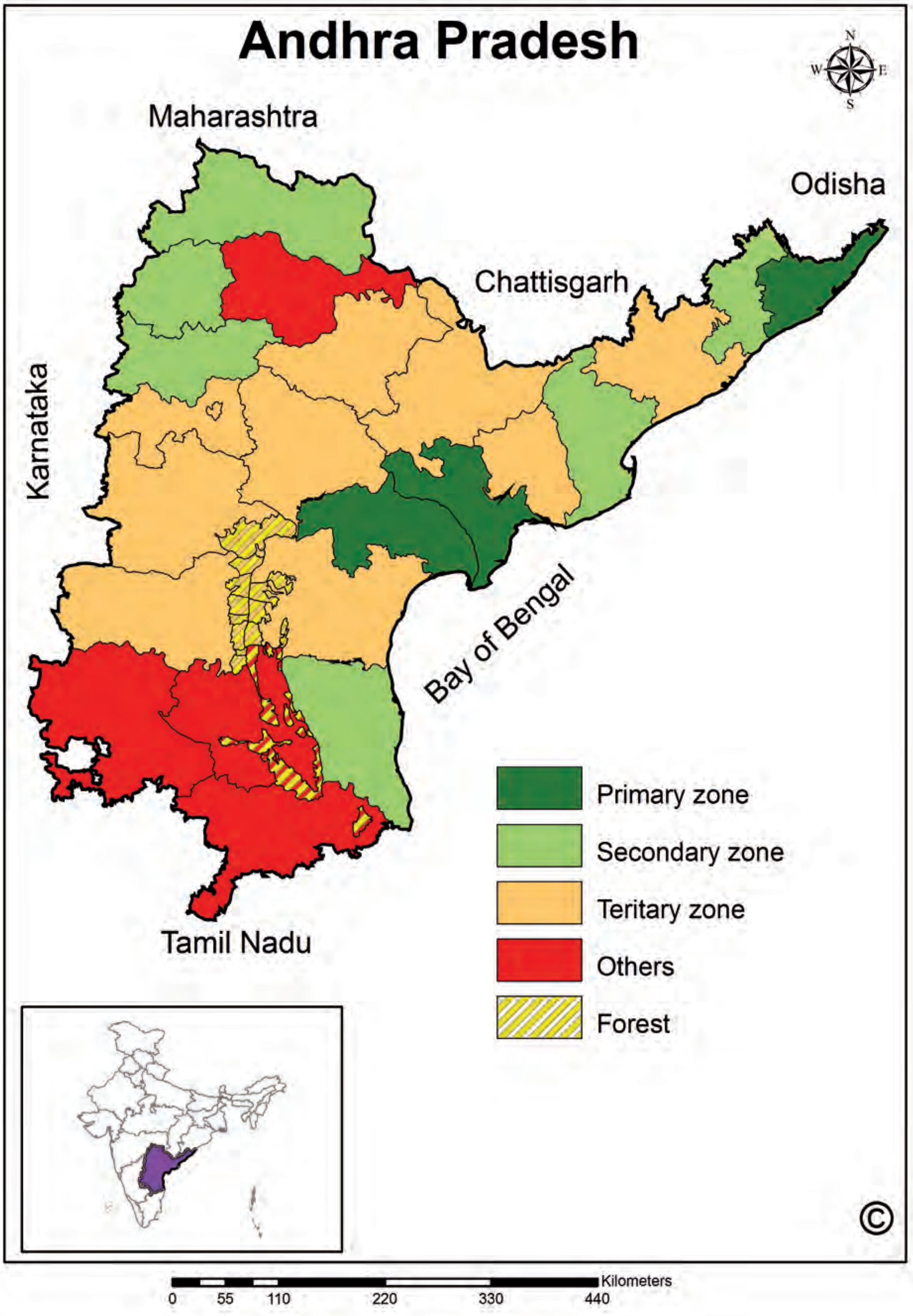


Fig. 30: Production zones of blackgram in Andhra Pradesh

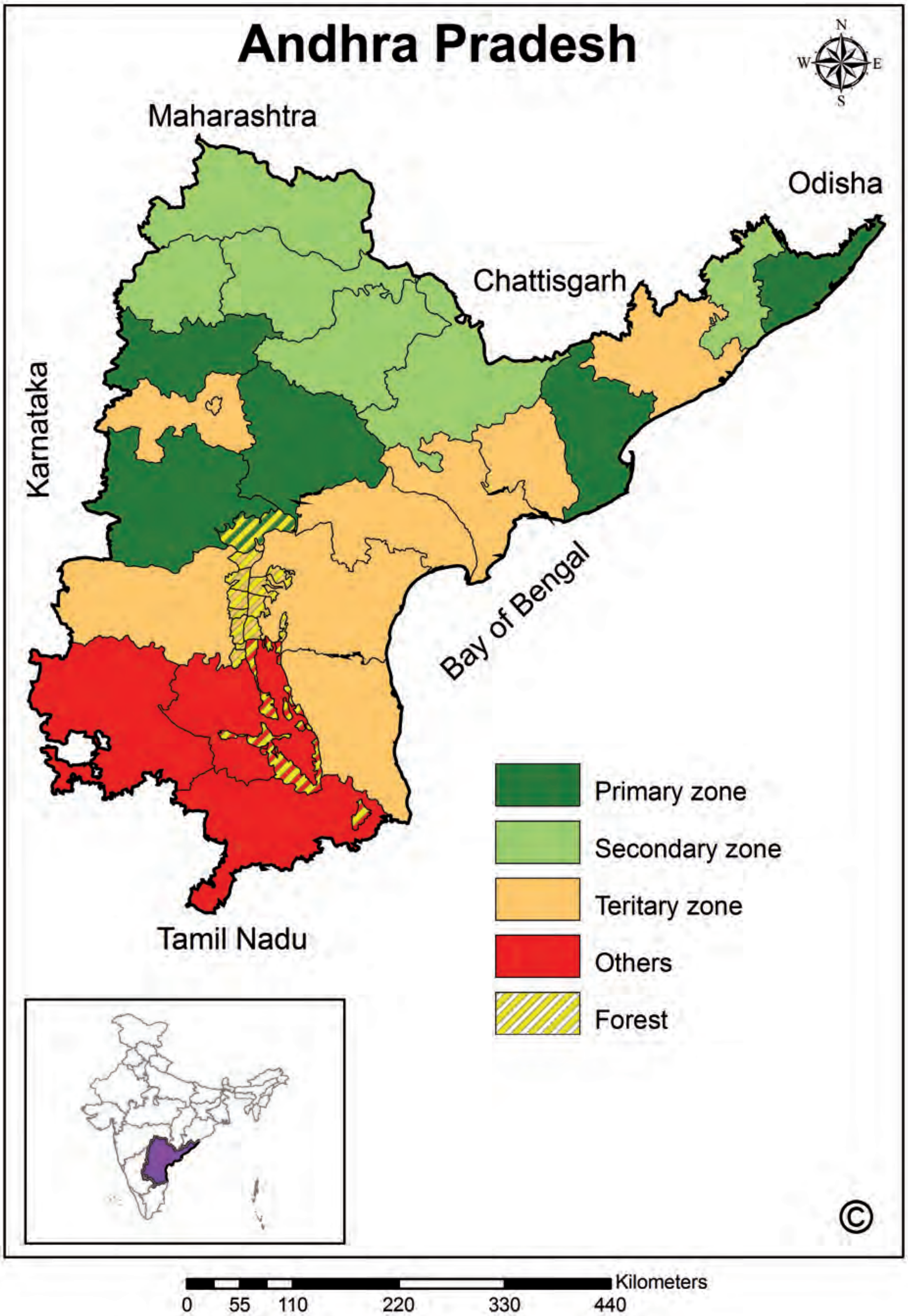


Fig. 31: Production zones of greengram in Andhra Pradesh

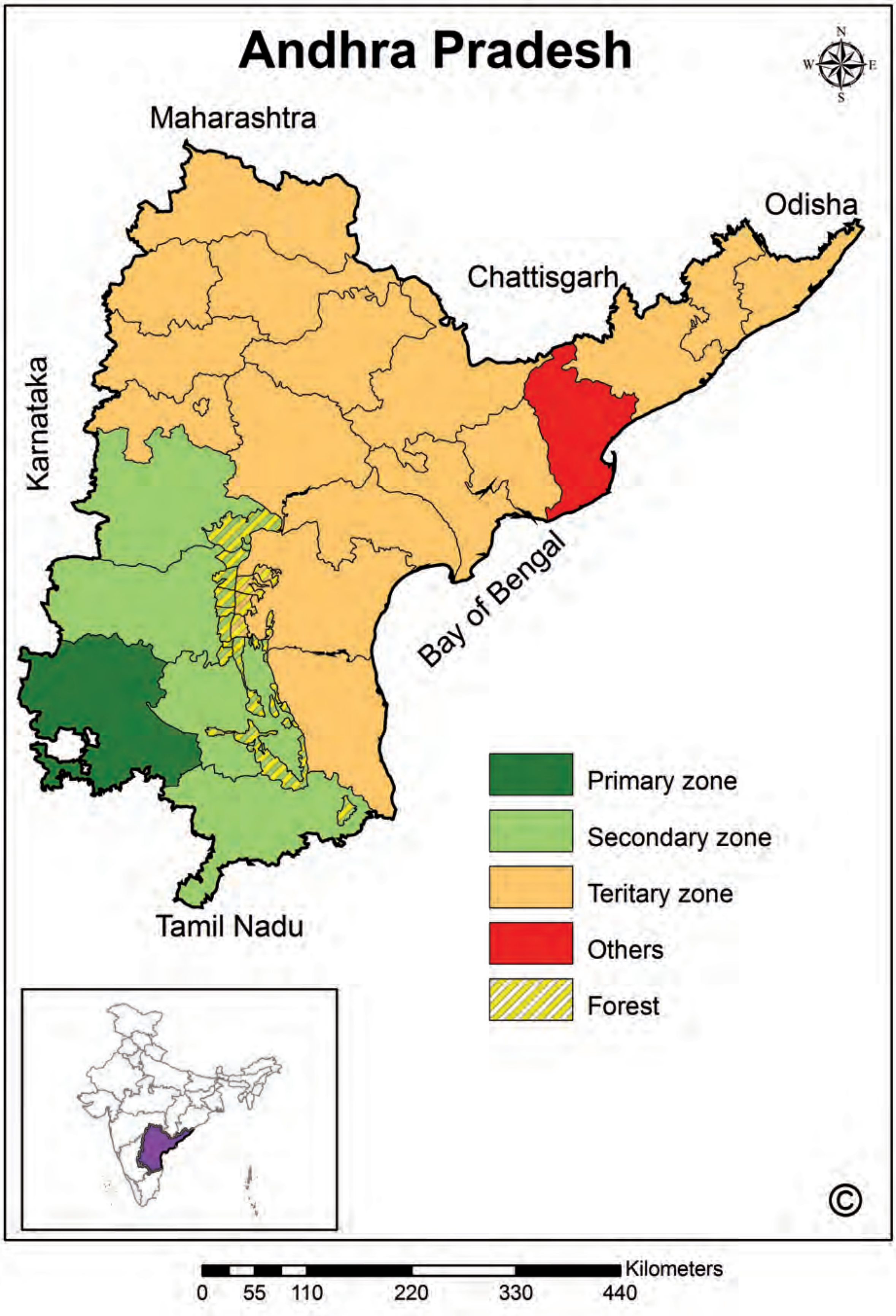


Fig. 32: Production zones of groundnut in Andhra Pradesh

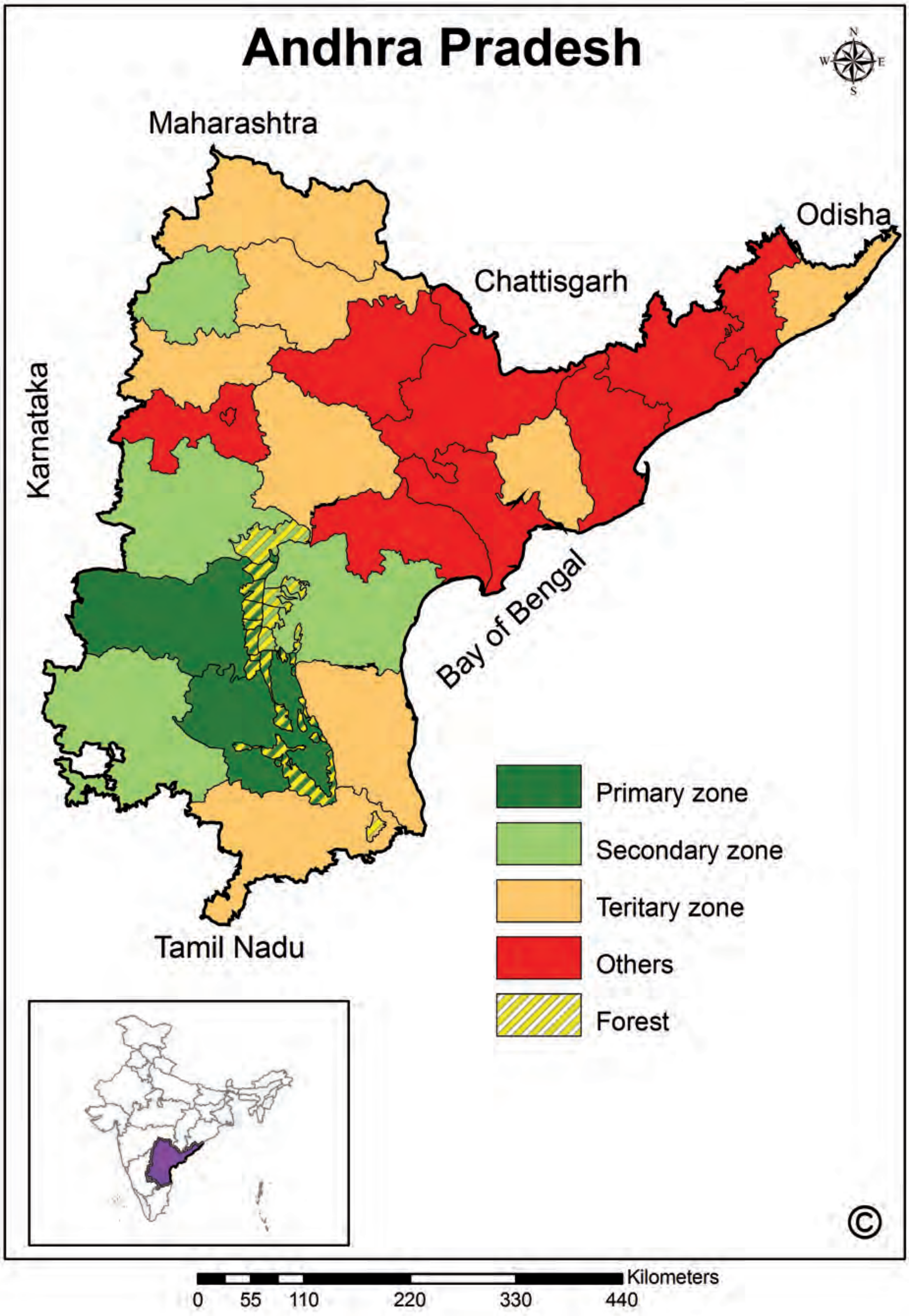


Fig. 33: Production zones of sunflower in Andhra Pradesh

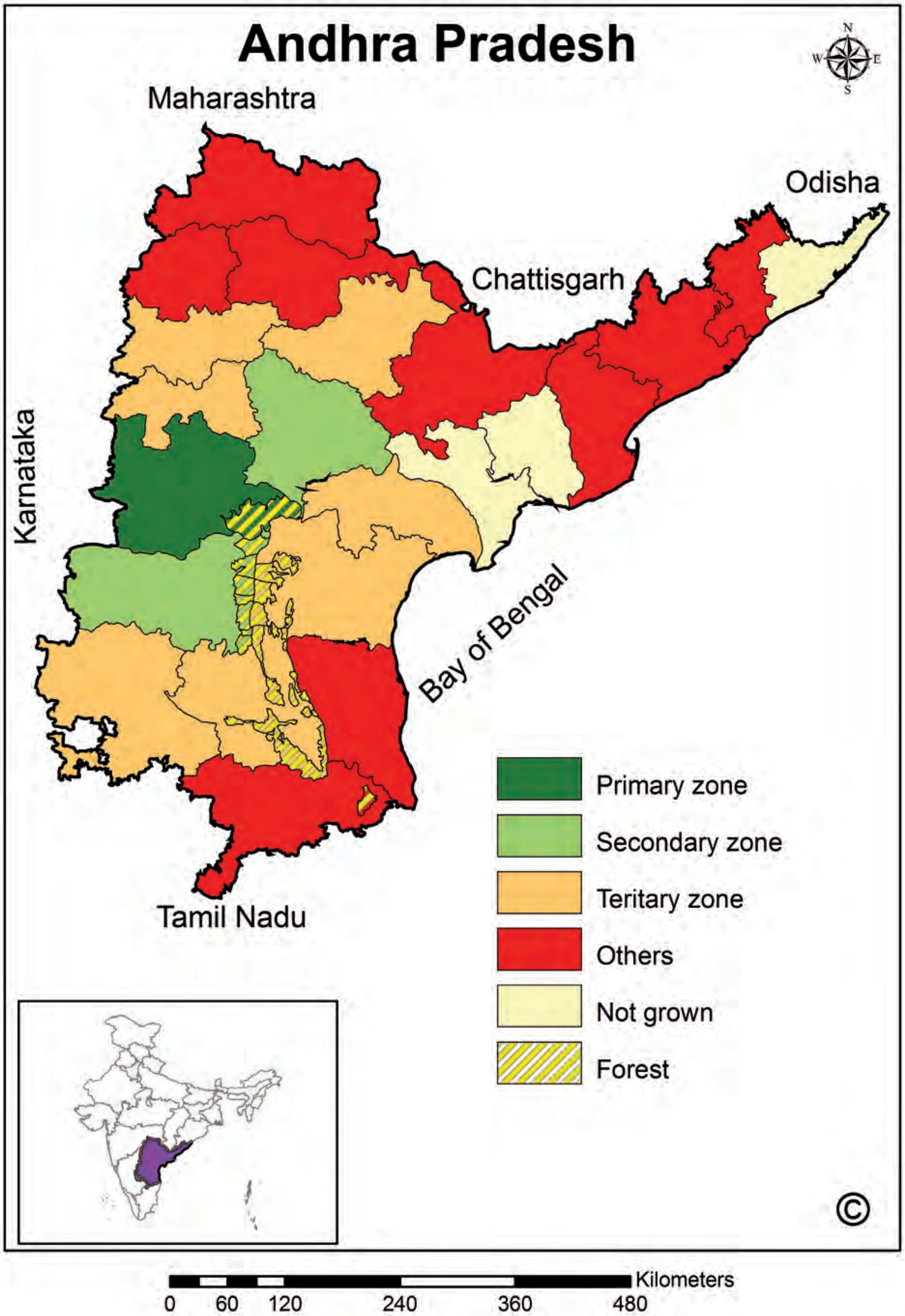


Fig. 34: Production zones of castor in Andhra Pradesh

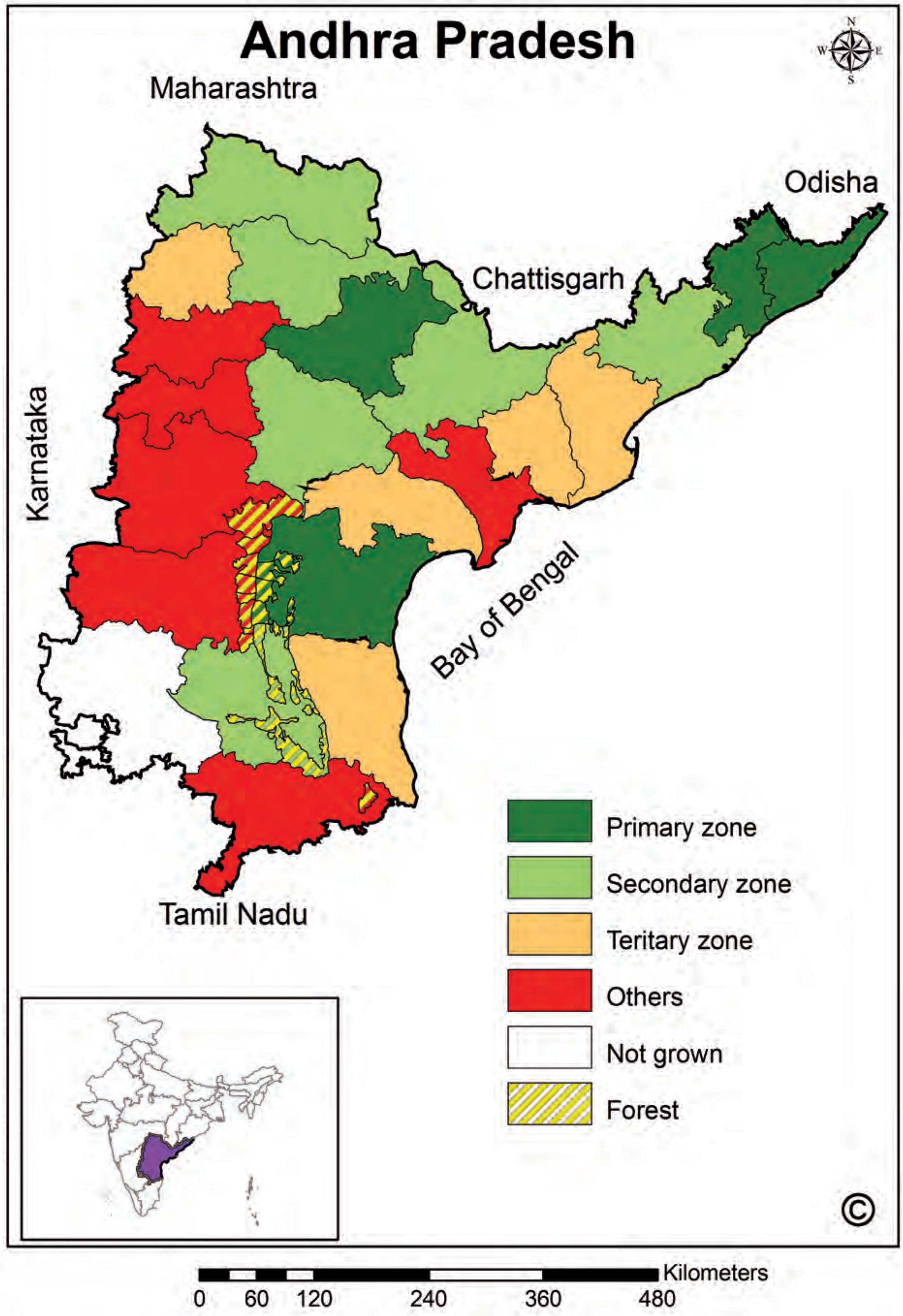


Fig. 35: Production zones of sesame in Andhra Pradesh

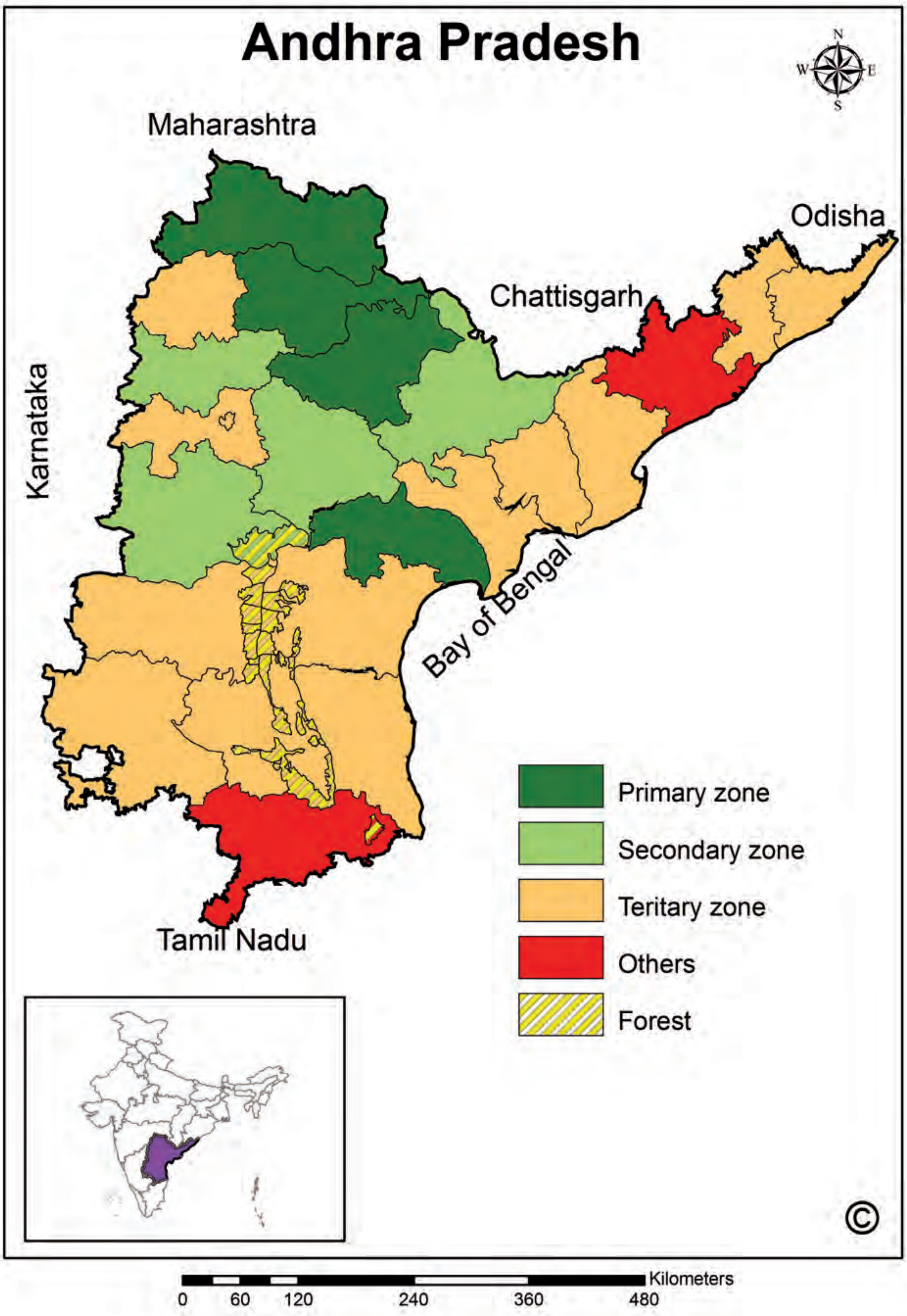


Fig. 36: Production zones of cotton in Andhra Pradesh

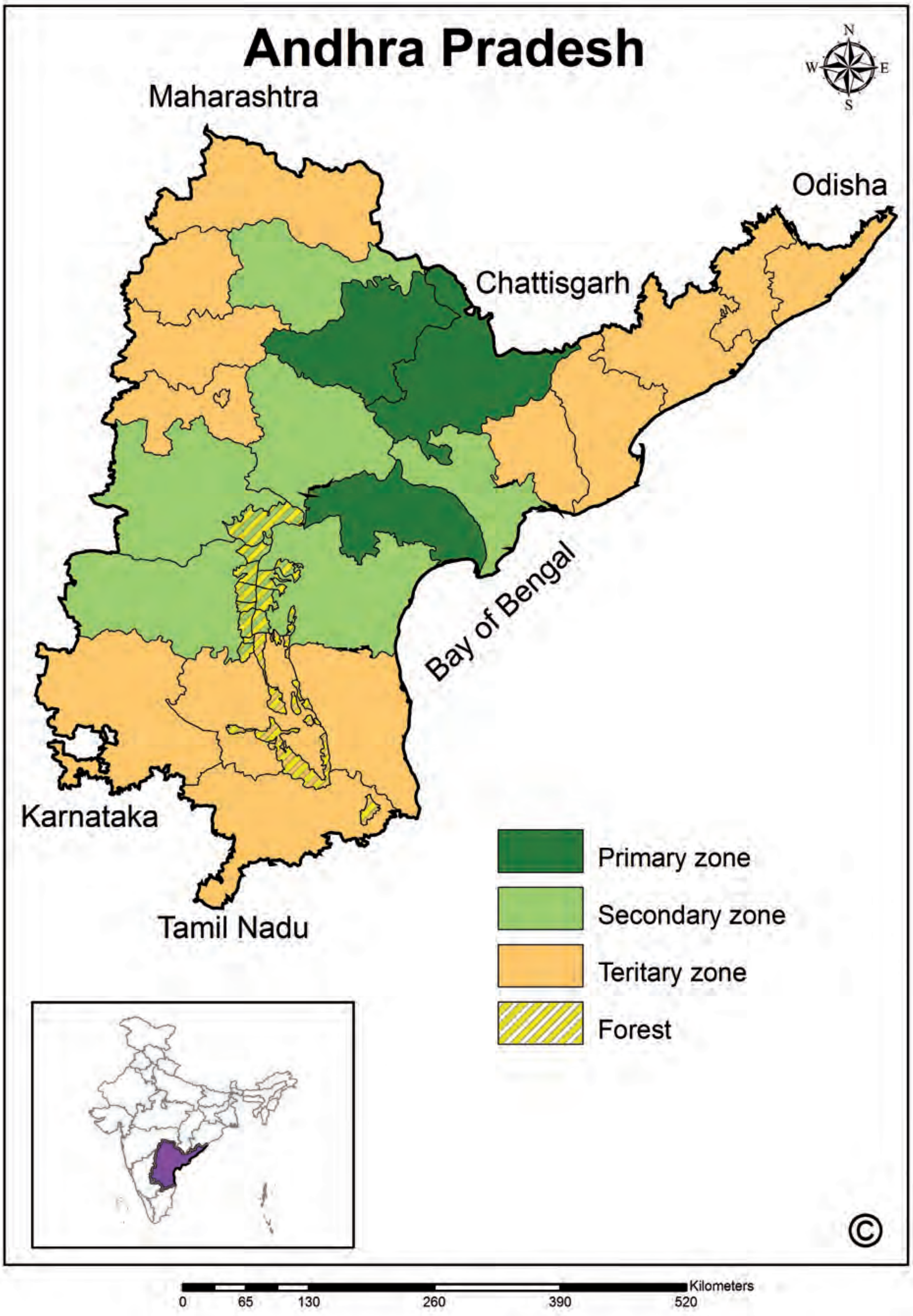


Fig. 37: Production zones of chillies in Andhra Pradesh

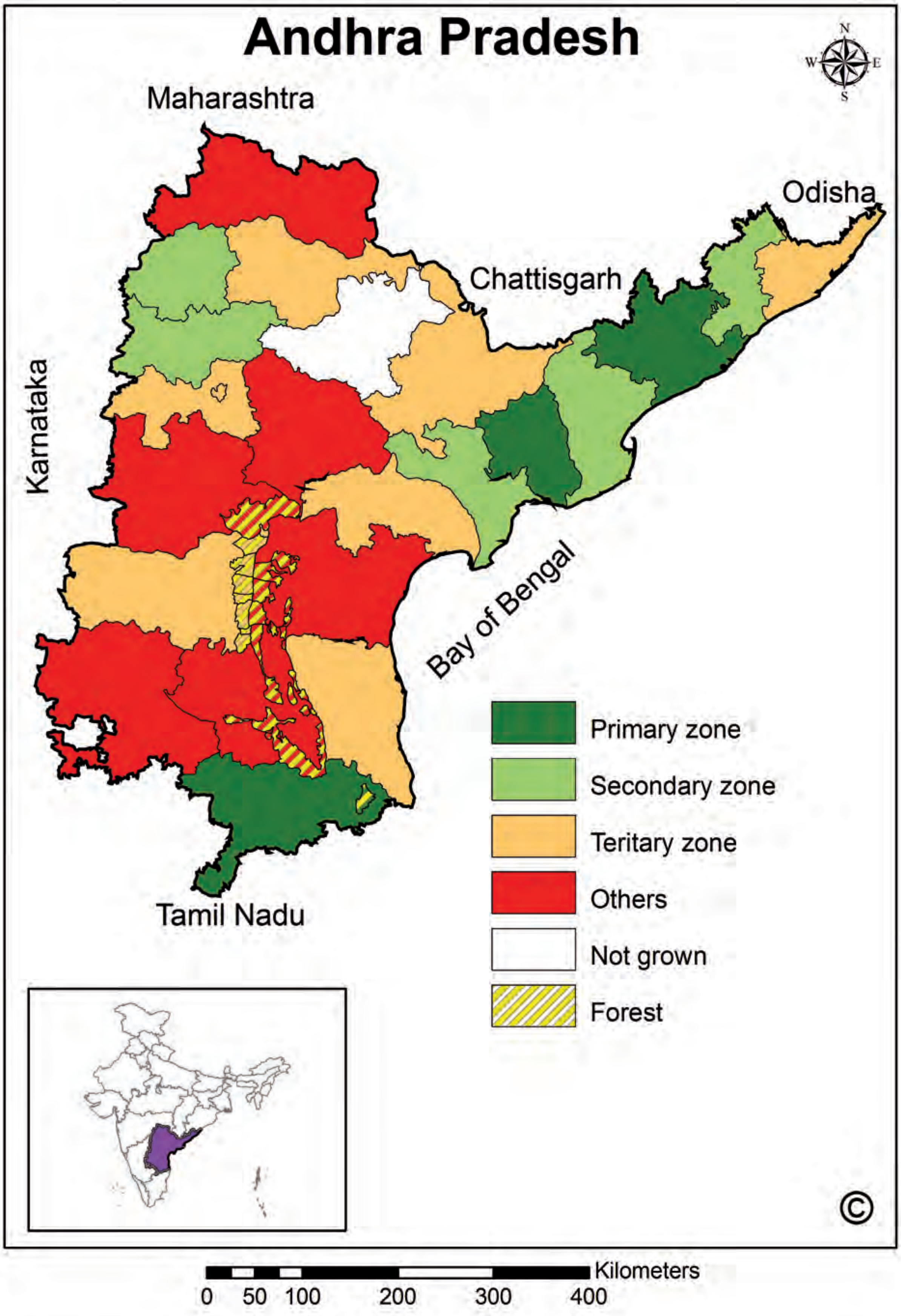


Fig. 38: Production zones of sugarcane in Andhra Pradesh

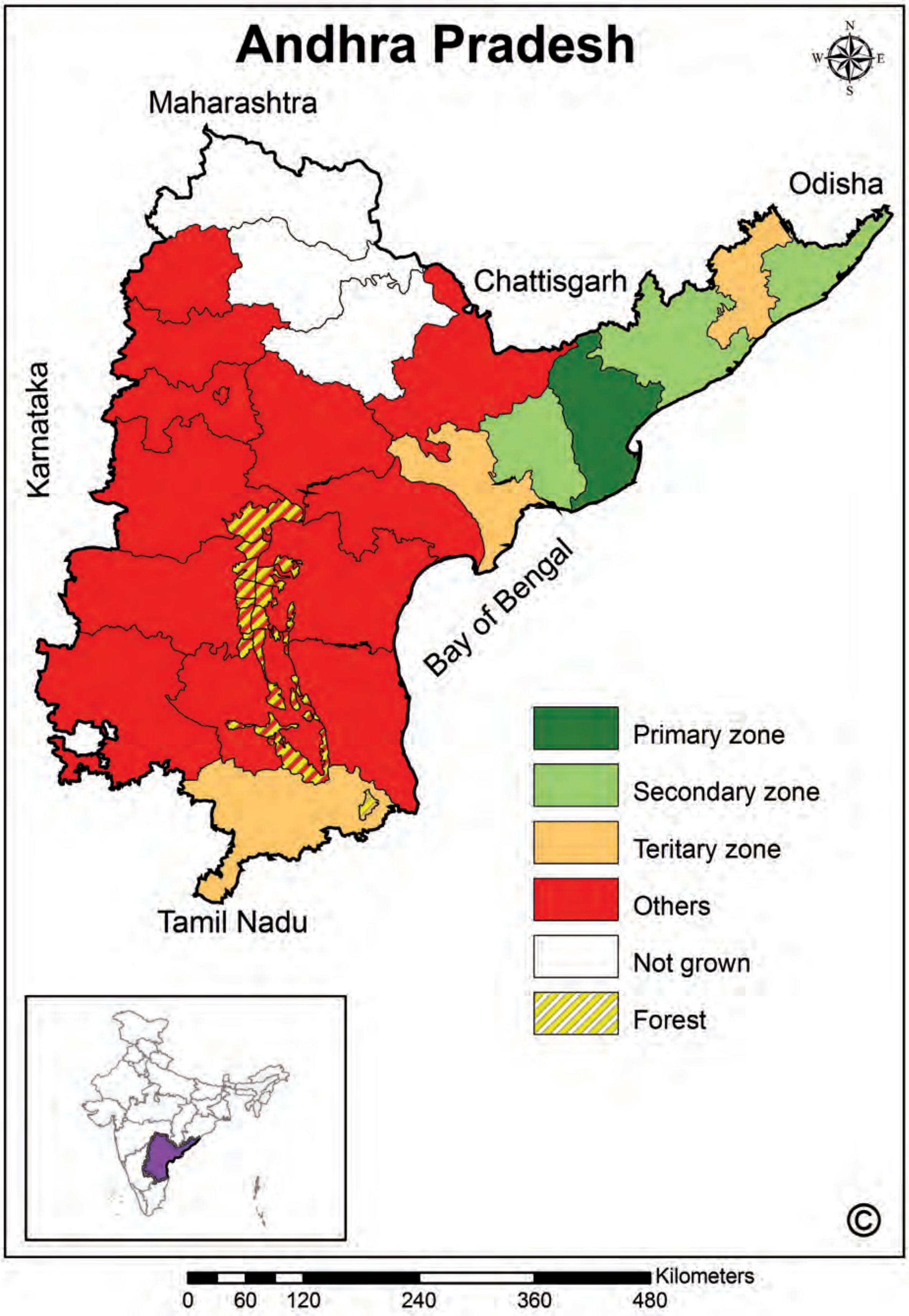


Fig. 39: Production zones of coconut in Andhra Pradesh

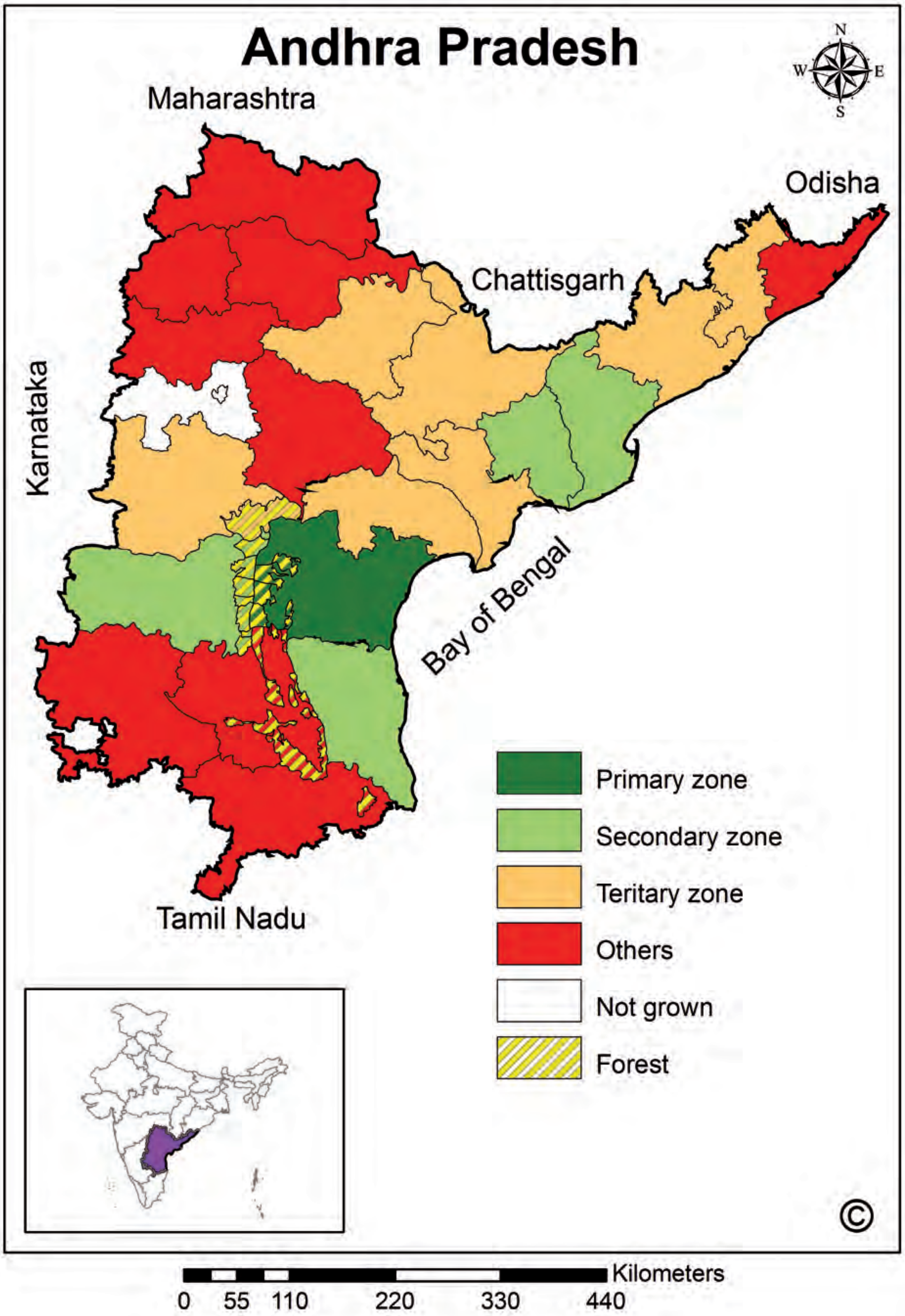


Fig. 40: Production zones of tobacco in Andhra Pradesh

3.6. Demarcation of productivity (yield) zones

Yield gap analysis is done to quantify the difference between the potential productivity of a crop in a region and its yield at farm level. It helps in the development of suitable strategies to improve the production at farm level. Though the yield gap analysis is generally done using experimental data, an attempt is made here to identify the regions with high productivity and regions with low productivity retaining heterogeneity of practical farming at district level. This comparison may ultimately result in identifying production constraints so as to bring all the zones to higher productivity levels. The criteria adopted in the demarcation of the zones is based on area as well as yield of different crops. It is presented in Table 5. In case of paddy, scope for the improvement of productivity exists in Visakhapatnam, Adilabad, Ranga Reddy and YSR Kadapa districts (Fig. 41).

District are placed in different categories depending upon the area and productivity levels and nine categories are considered *viz.,* High area-High yield (HH), High area - Medium yield (HM), High area - Low yield (HL), Medium area - High yield (MH), Medium area - Medium yield (MM), Medium area - Low yield (ML), Low area - High yield (LH), Low area - Medium yield (LM) and Low area - Low yield (LL). Depending upon the availability of water resources, management strategies may have to be evolved to bridge the gap in yield levels. The area under maize is sufficiently large in Mahabubnagar, Medak and Warangal districts, further planning is required to improve its productivity by taking a cue from SPSR Nellore, Prakasam and East Godavari districts (Fig. 42).

In Vizianagaram district though a phenomenal rise in maize sown area is evident, in recent years, the yield levels are well below the potential hence this calls for the introduction of a scientific approach. Like-wise scope exists for yield improvement in sorghum in Anantapur, Mahabubnagar and Nalgonda districts. Incentives like seed and fertilizer at subsidized rates and enhancement in MSP may aid in increasing its area in districts like SPSR Nellore and West Godavari (Fig. 43).

Production and productivity of pulses like pigeonpea, chickpea, blackgram and greengram showed that more area under pigeonpea may be encouraged in the north coastal zone and Guntur districts (Fig. 44). The productivity of blackgram in paddy fallows of Guntur district are declining in recent years, and the introduction of high yielding and disease resistant cultivars may help to bridge the yield gap compared to that in the adjacent Krishna district (Fig. 45).

However, scope exists to improve the productivity of blackgram growing areas in Vizianagaram and Srikakulam districts. In case of greengram, Vizianagaram, Krishna, Adilabad, Karimnagar and Nizamabad are leading production districts. Greengram may be promoted, in place of blackgram, in the West Godavari district considering yield differences (Fig. 46). Cultivation of chickpea is mostly prevailing in the state on vertisols/vertic soils where the crop grown in residual moisture during *rabi* (Fig. 47).

Among oilseed crops, groundnut, though grown largely in Anantapur, YSR Kadapa and Kurnool districts, its yields are low compared to Mahabubnagar and Chittoor districts (Fig. 48). Yield levels can be improved through the adoption of rain water conservation and the introduction of cultivars which can stand >40 days mid-season drought as the rainfall is highly erratic in these districts during the SW monsoon rainy season. Yield levels in north coastal districts, as well as, Nalgonda, Warangal and Karimnagar districts are of concern as substantial area is devoted to the crop.

Wide yield gap exists between productivity levels in castor in Mahabubnagar district and its neighbouring Prakasam, Guntur and Nalgonda districts (Fig. 49). Like-wise in sesame, the yield gap between Adilabad and its neighbouring Nizamabad and Karimnagar districts needs to be bridged with the introduction of appropriate technology (Fig. 50).

Productivity levels of sugarcane are highly variable among the major cane growing districts; the low productivity levels in Vizianagaram, Nizamabad and West Godavari districts require a special attention (Fig. 51). Cotton, another commercial crop shows wide scope for yield improvement in Mahabubnagar, Kurnool and YSR Kadapa and to some extent in Ranga Reddy, Medak and Nizamabad districts (Fig. 52). Though substantial area is under chillies crop in districts like Krishna, Nalgonda and Mahabubnagar the productivity levels are low giving scope for some interventions (Fig. 53).

Table 5: Criteria adopted for categorization of productivity zones of different crops

Crops	Area (ha)			Yield (kg ha^{-1})		
	High	Medium	Low	High	Medium	Low
Paddy	>2 lakh	1-2 lakh	<1 lakh	>3500	2500-3500	<2500
Maize	>50000	10000-50000	<10000	>6000	4000-6000	<4000
Sorghum	>10000	1000-10000	<1000	>2000	1000-2000	<1000
Pigeonpea	>30000	10000-30000	<10000	>600	400-600	<400
Chickpea	>50000	10000-50000	<10000	>1500	1000-1500	< 1000
Green gram	>20000	10000-20000	<10000	>400	300-400	<300
Black gram	>50000	10000-50000	<10000	>600	500-600	<500
Groundnut	>50000	10000-50000	<10000	>2000	1000-2000	<1000
Castor	>10000	1000-10000	<1000	>600	500-600	<500
Sesame	>5000	1000-5000	<1000	>400	200-400	<200
Cotton	>100000	10000-100000	<10000	>3 bales ha^{-1}	2-3	<2
Sugarcane	>20000	10000-20000	<10000	>90000	80-90000	<80000
Chilly	>10000	2000-10000	<2000	>3500	2500-3500	<2500

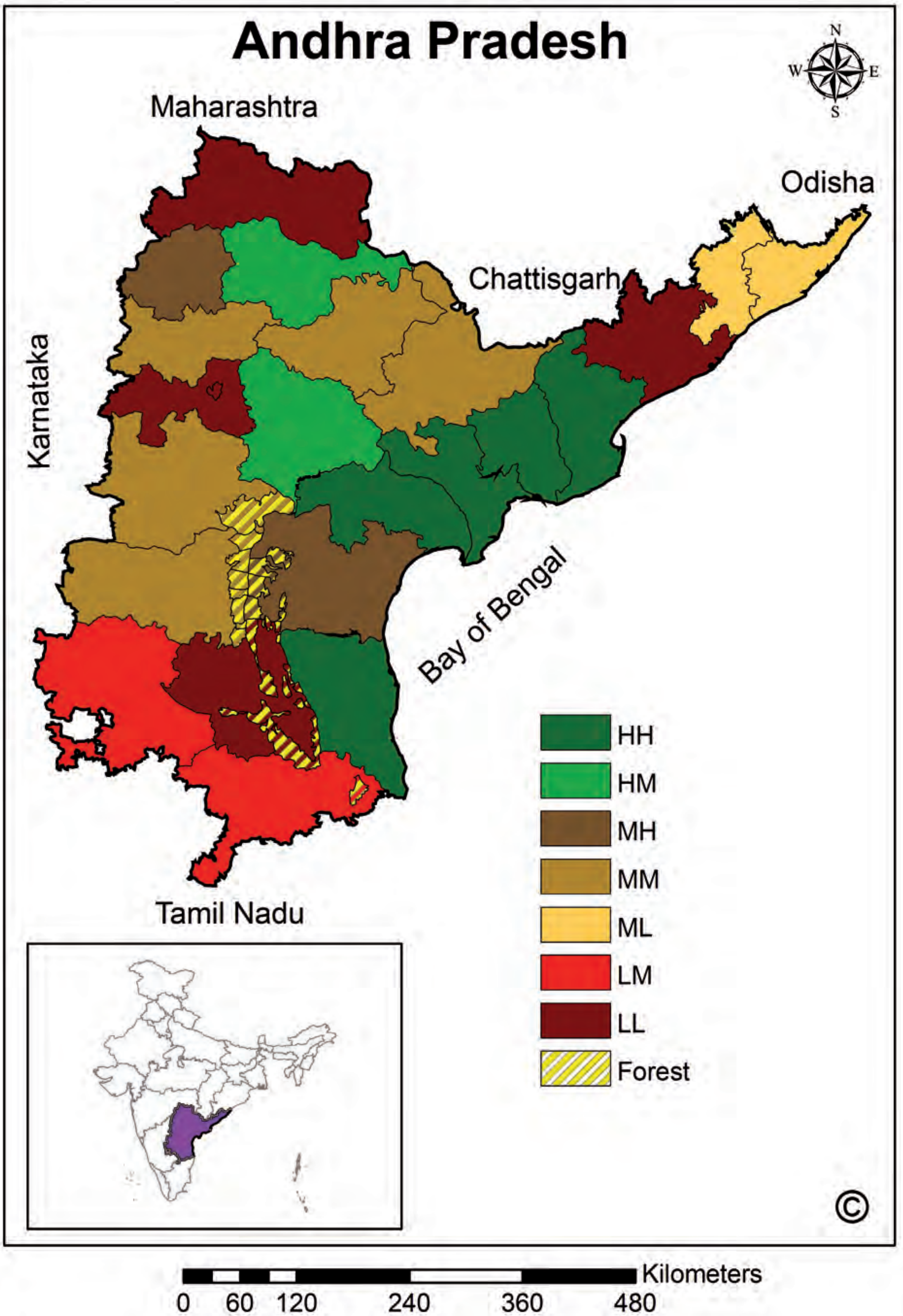


Fig. 41: Delineation of different productivity zones of paddy (See text for abbreviation of legends)

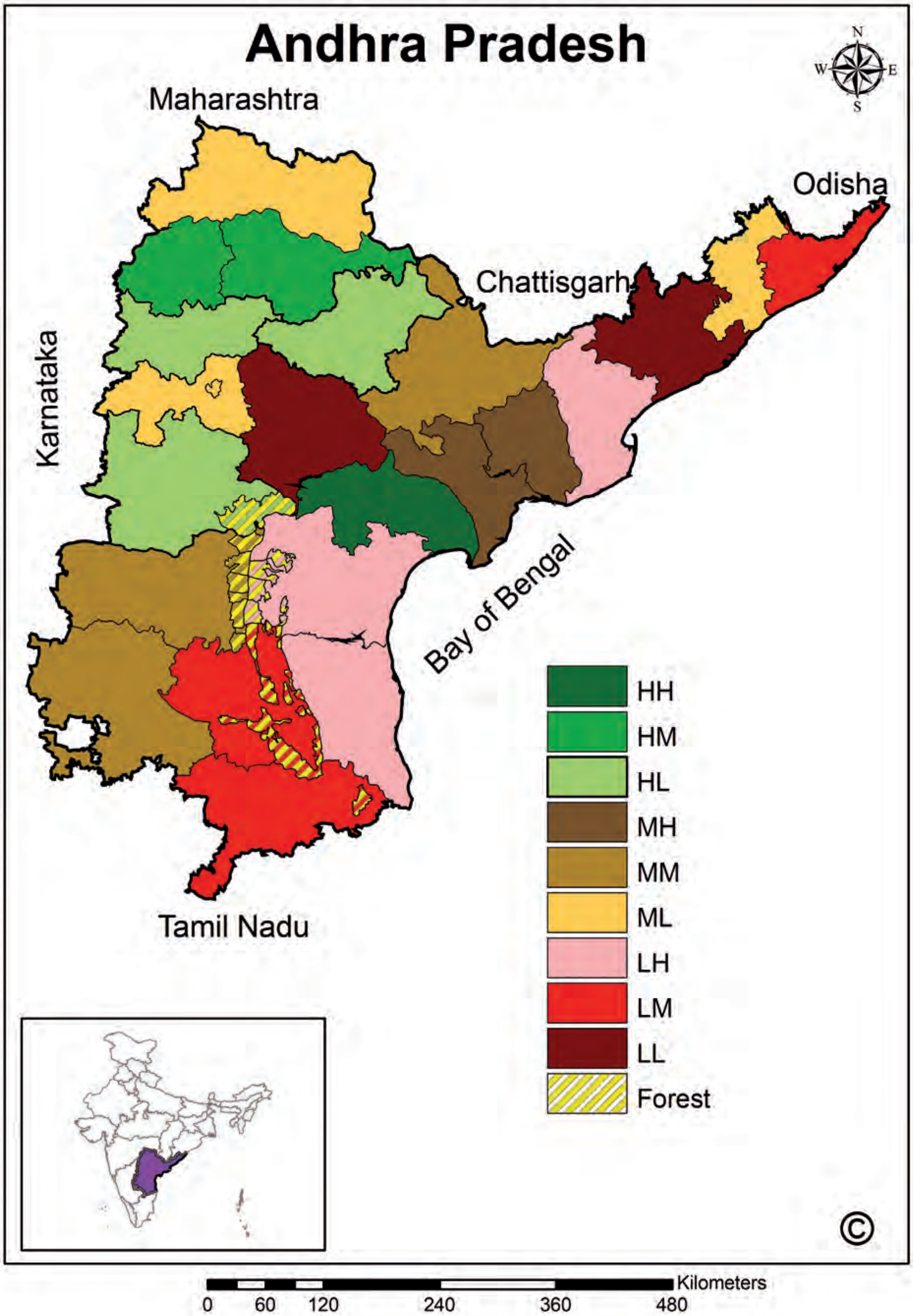


Fig. 42: Delineation of different productivity zones of maize
(See text for abbreviation of legends)

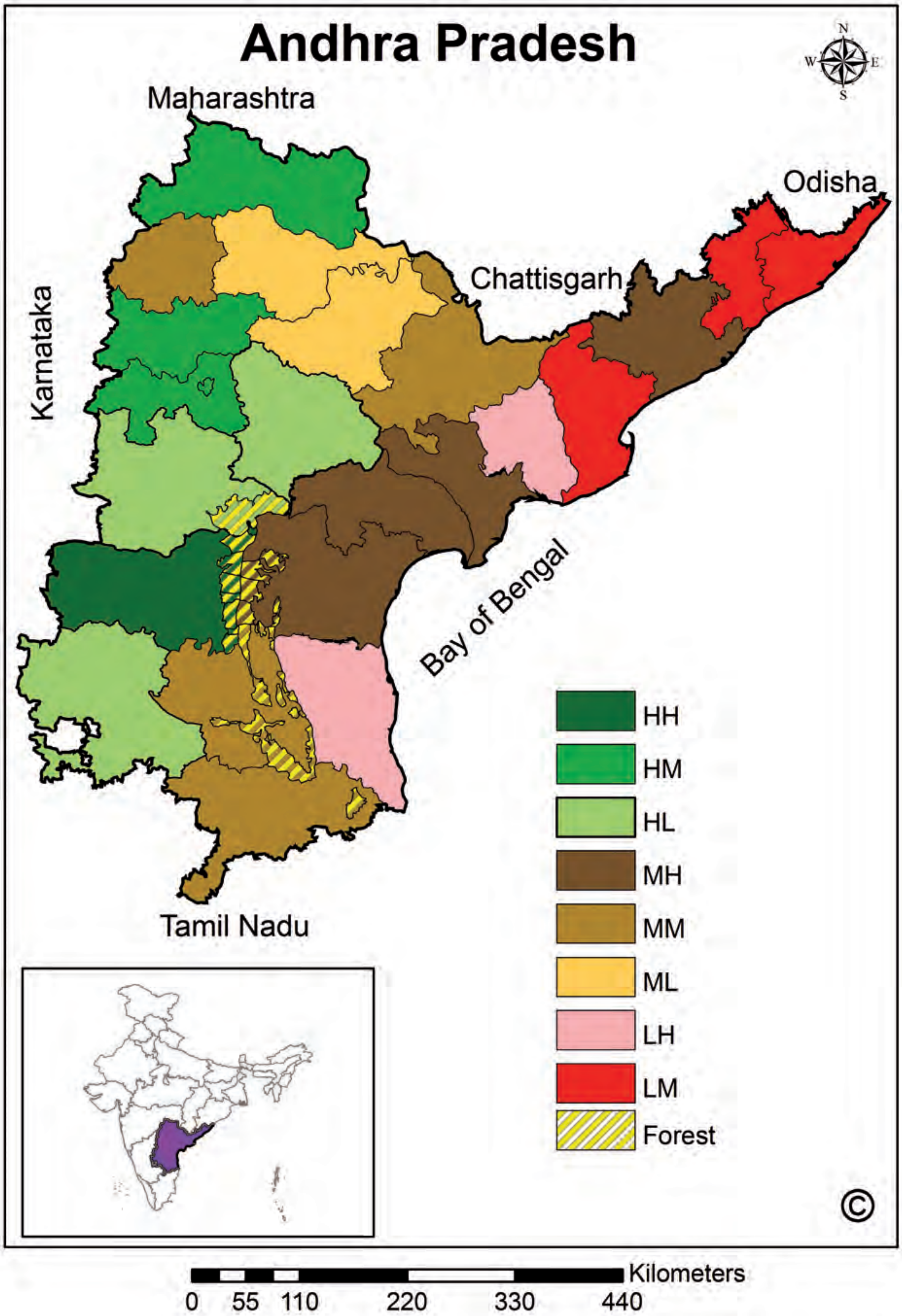


Fig. 43: Delineation of different productivity zones of sorghum
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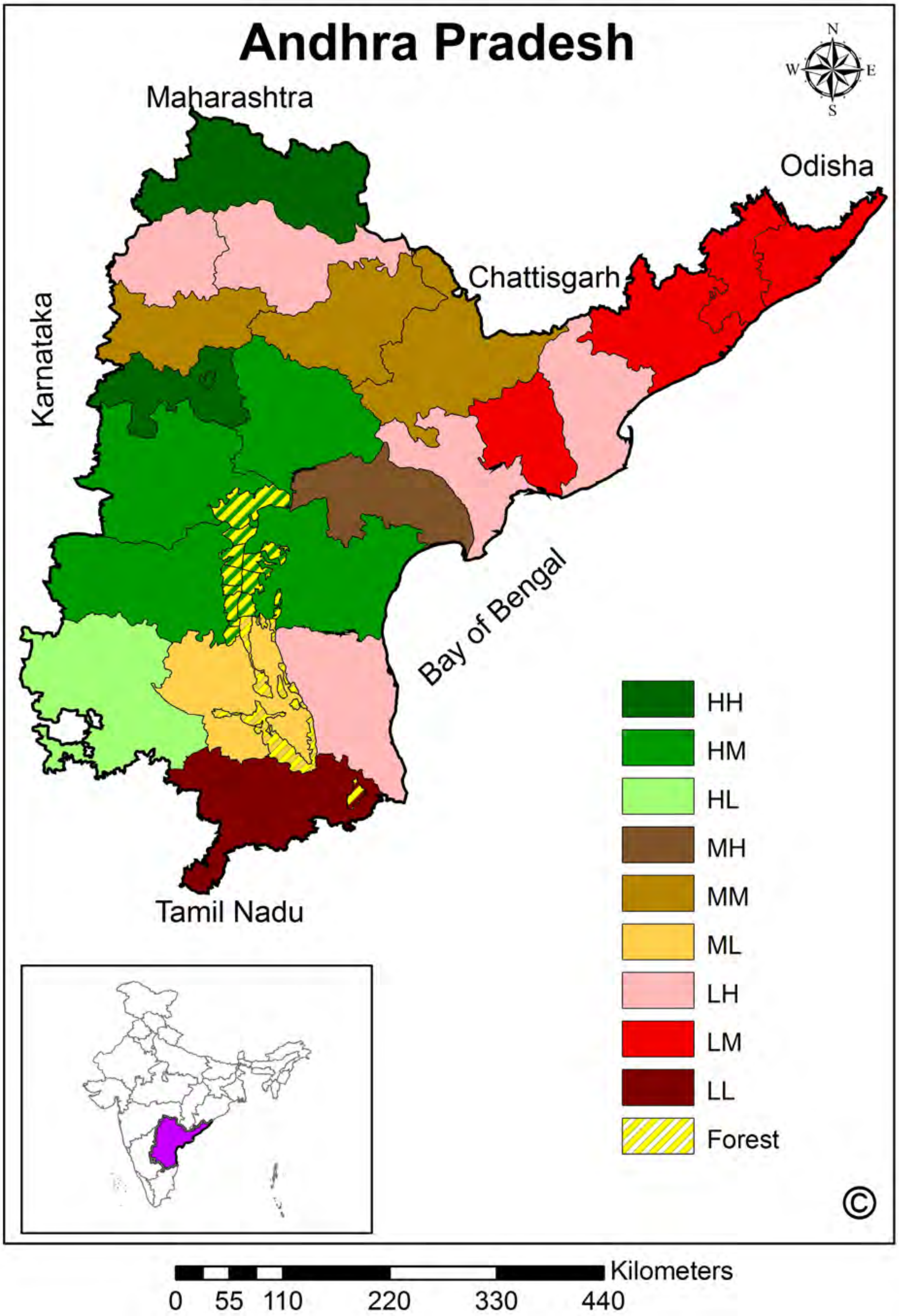

Fig. 44: Delineation of different productivity zones of pigeonpea
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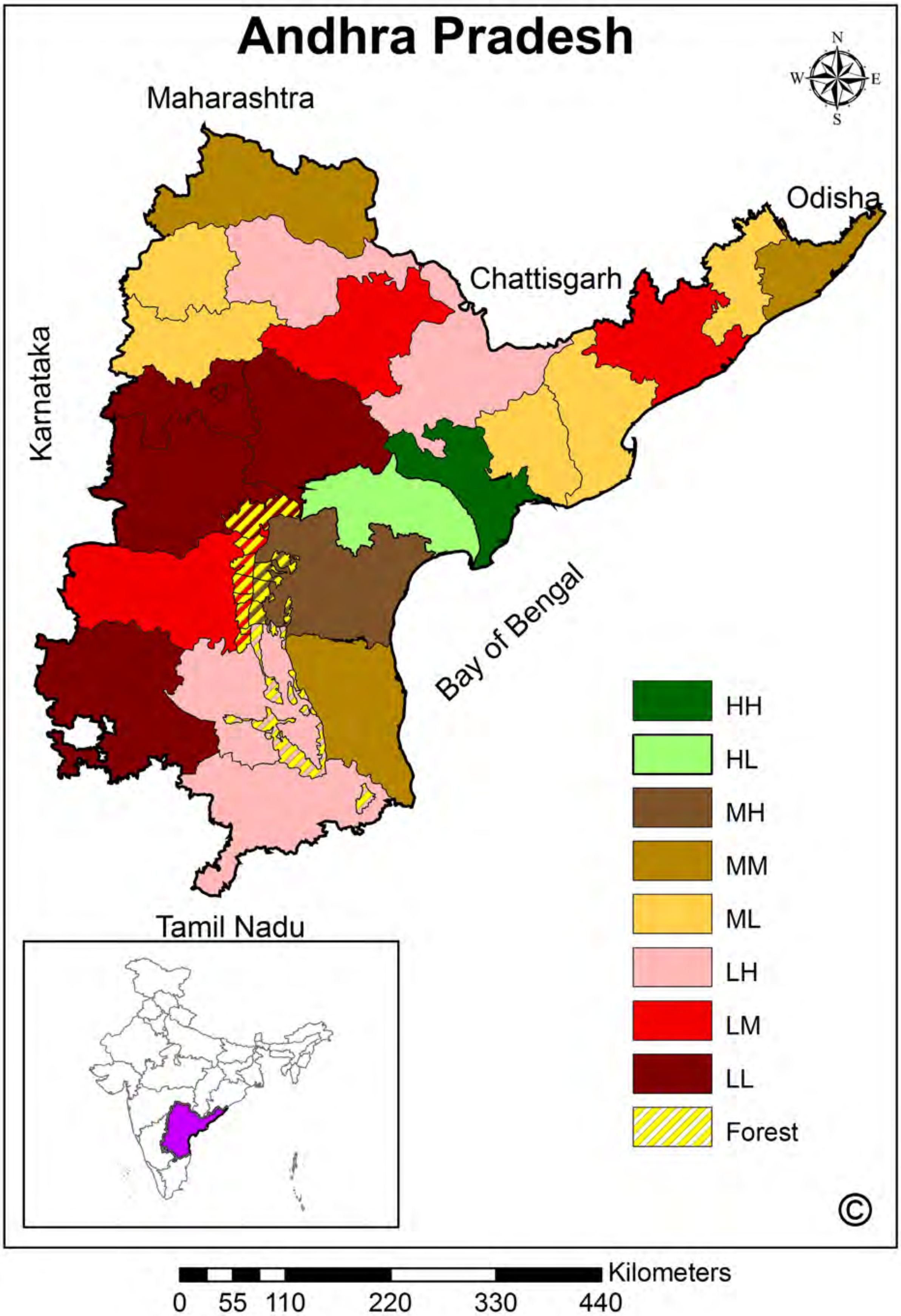

Fig. 45: Delineation of different productivity zones of blackgram
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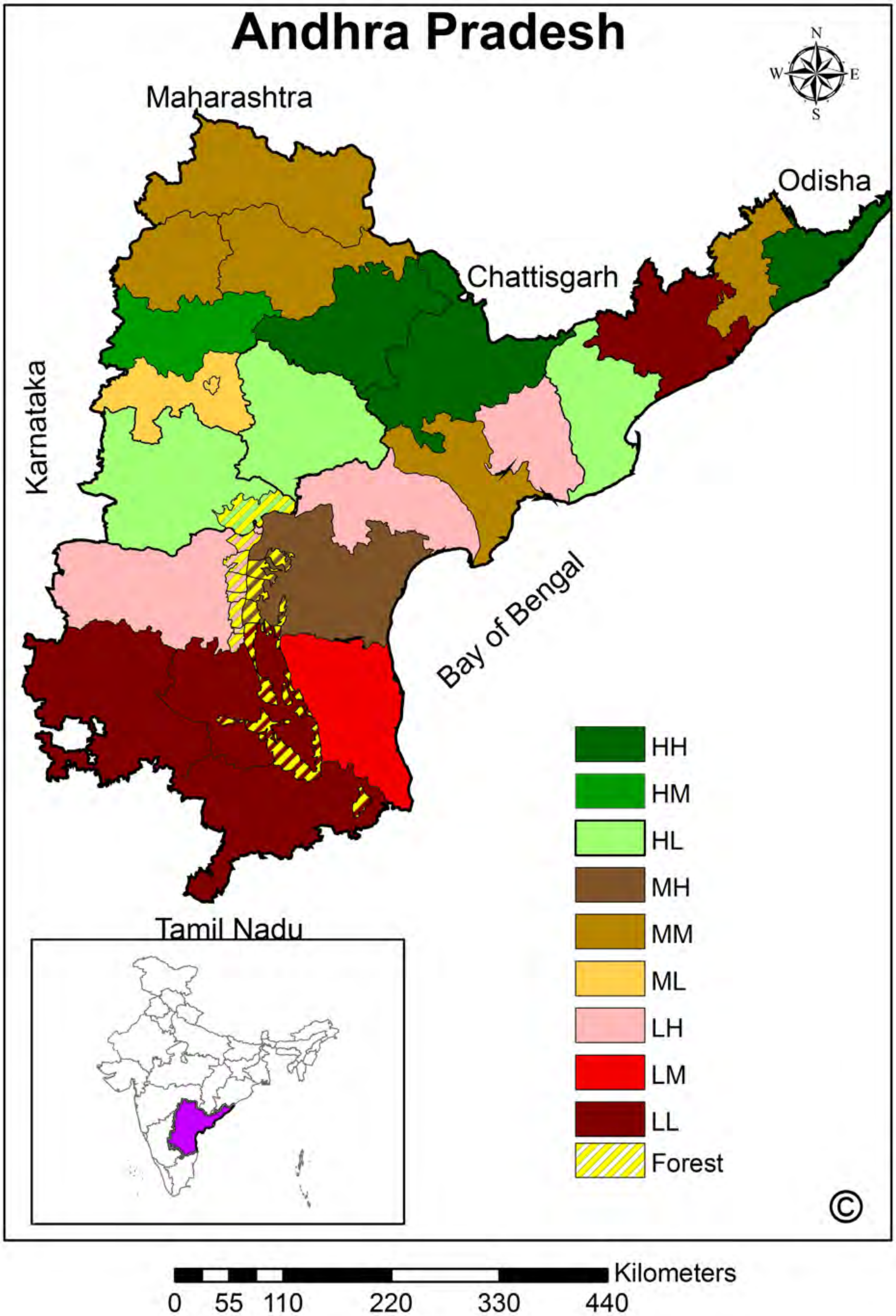

Fig. 46: Delineation of different productivity zones of greengram
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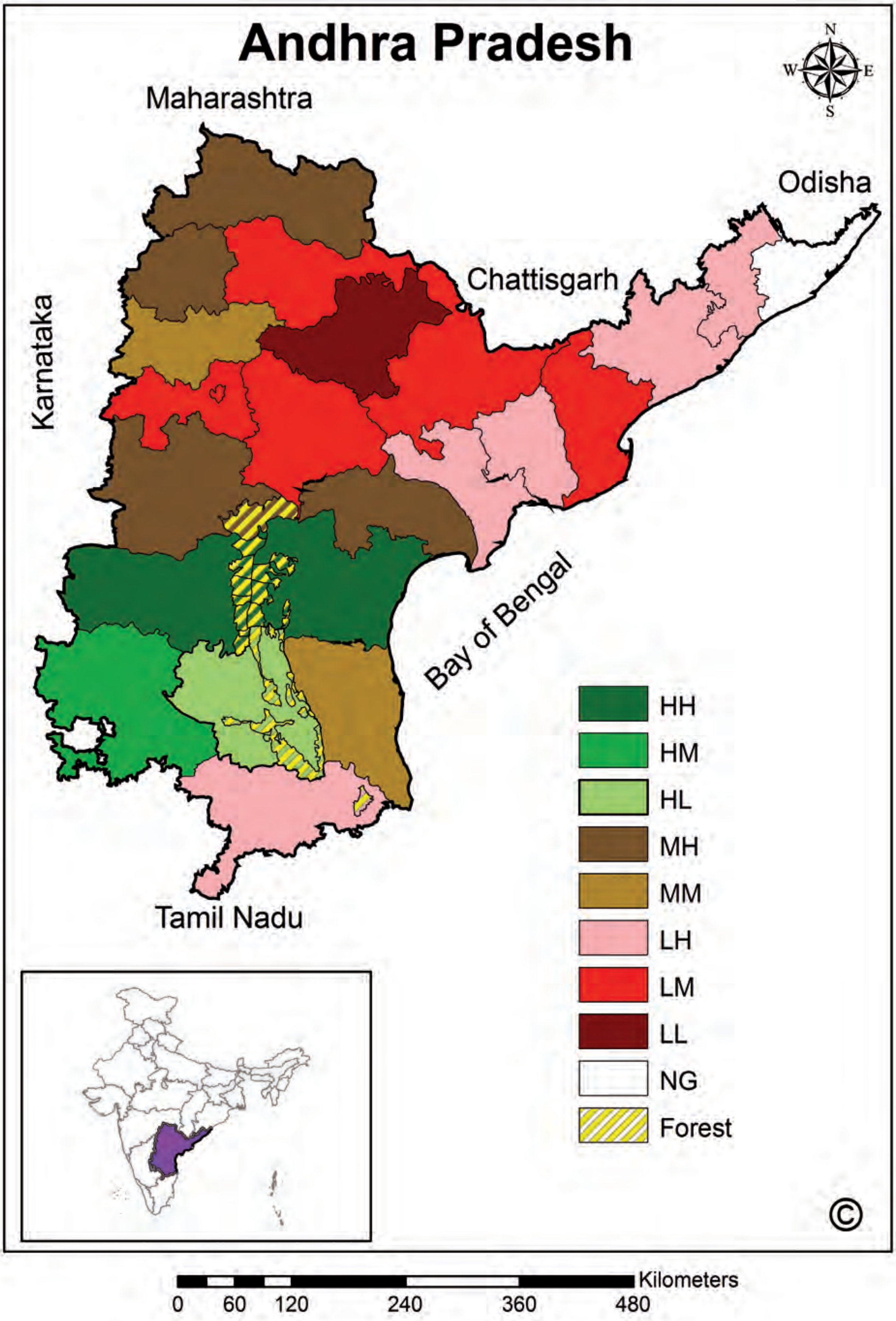

Fig. 47: Delineation of different productivity zones of chickpea
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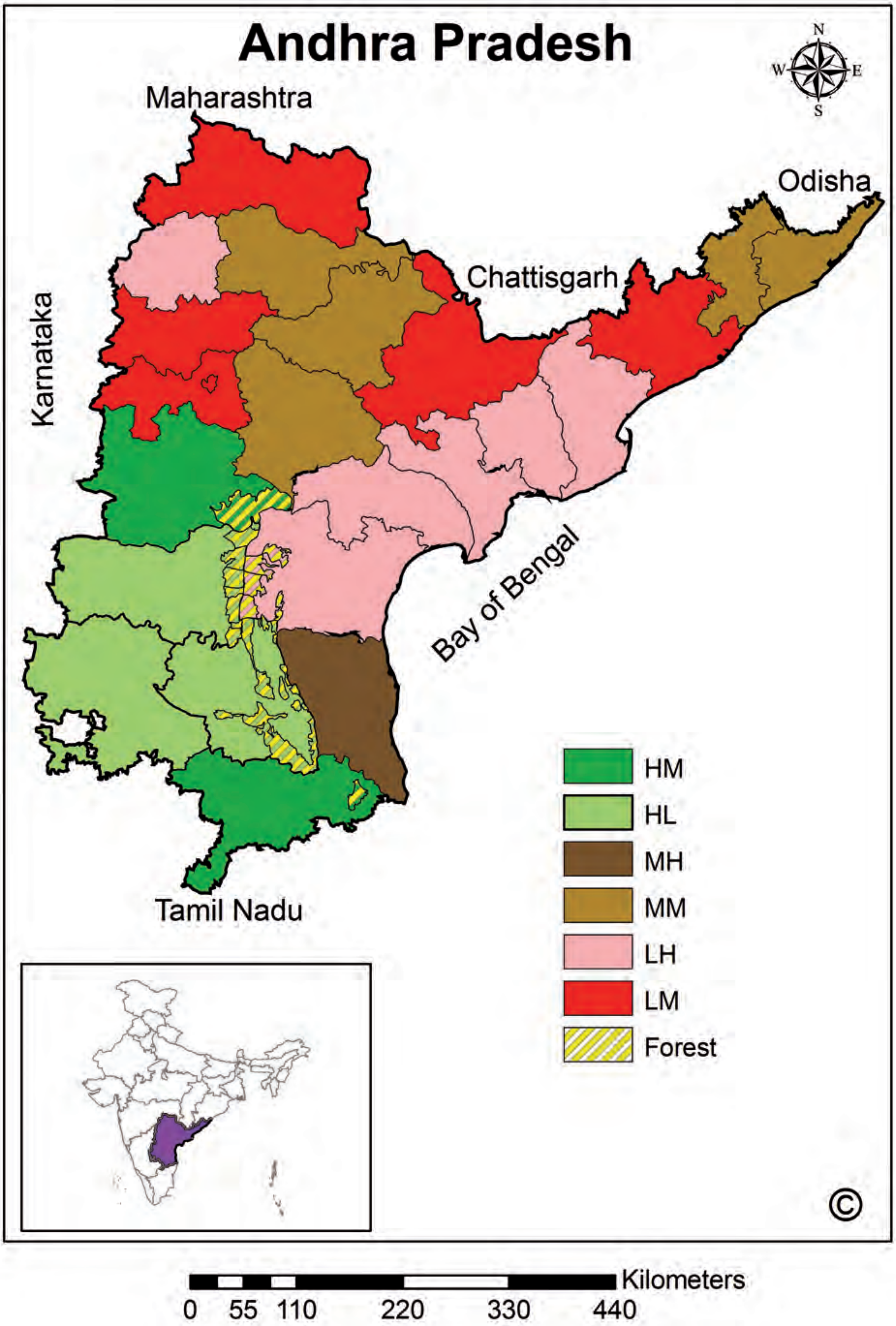

Fig. 48: Delineation of different productivity zones of groundnut
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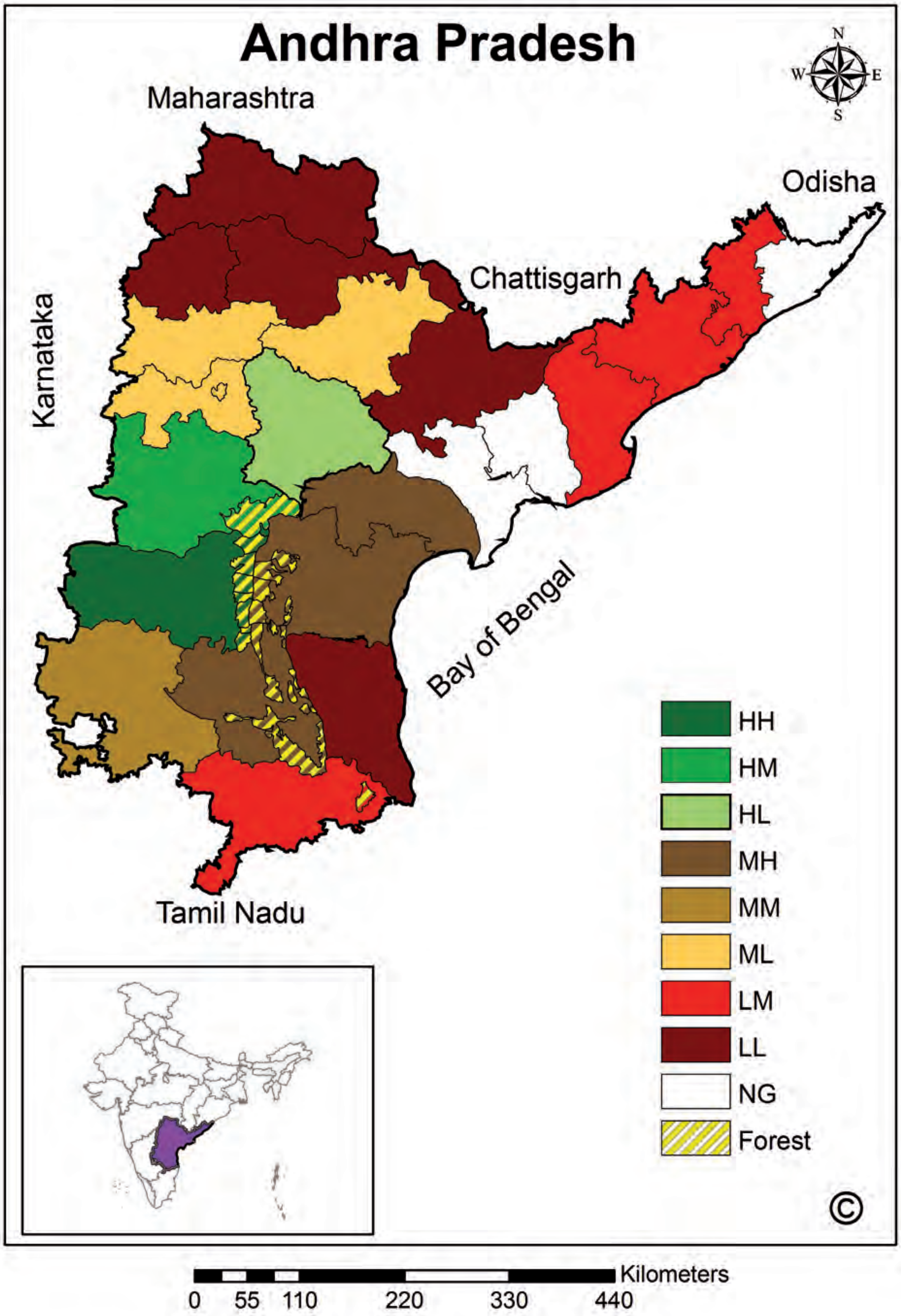

Fig. 49: Delineation of different productivity zones of castor
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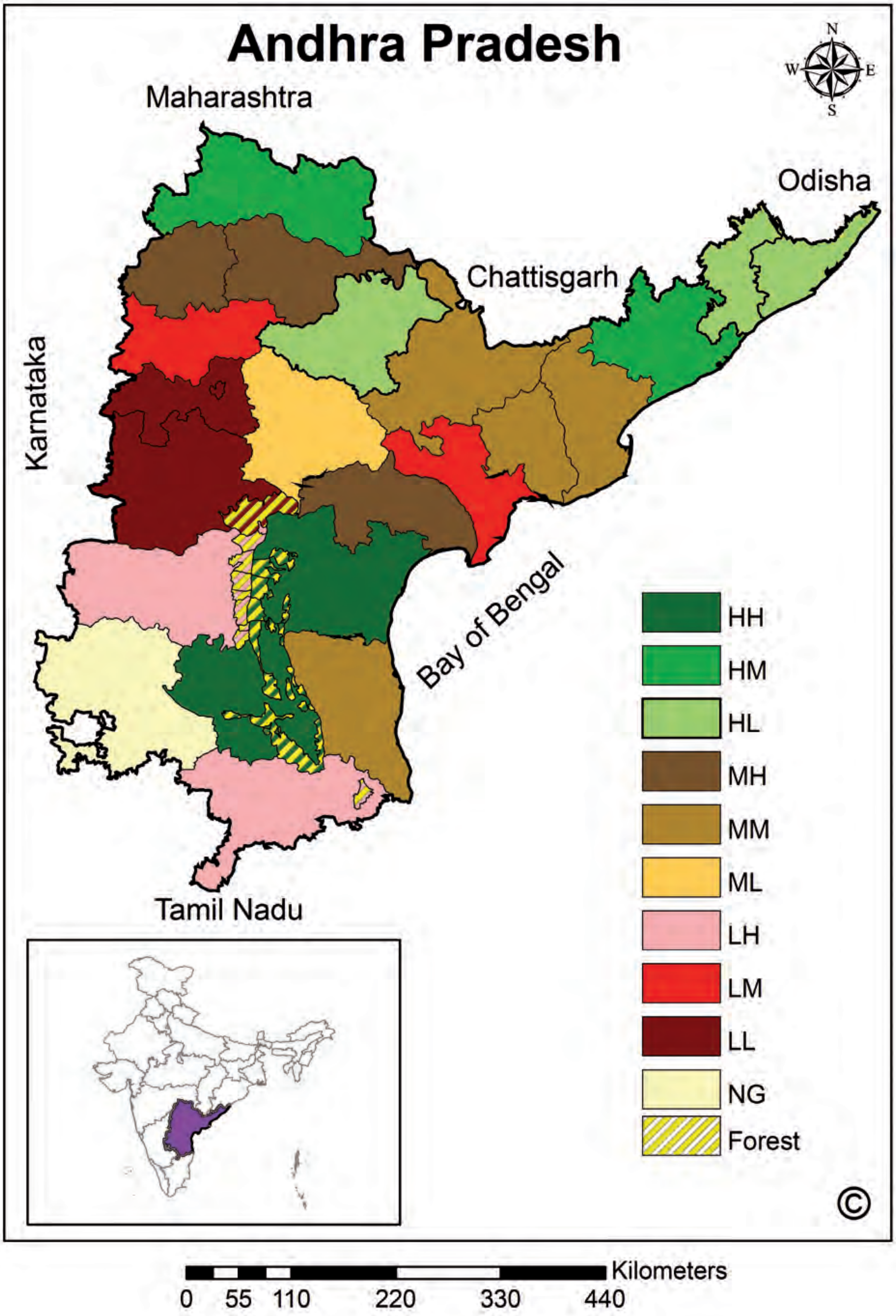

Fig. 50: Delineation of different productivity zones of sesame
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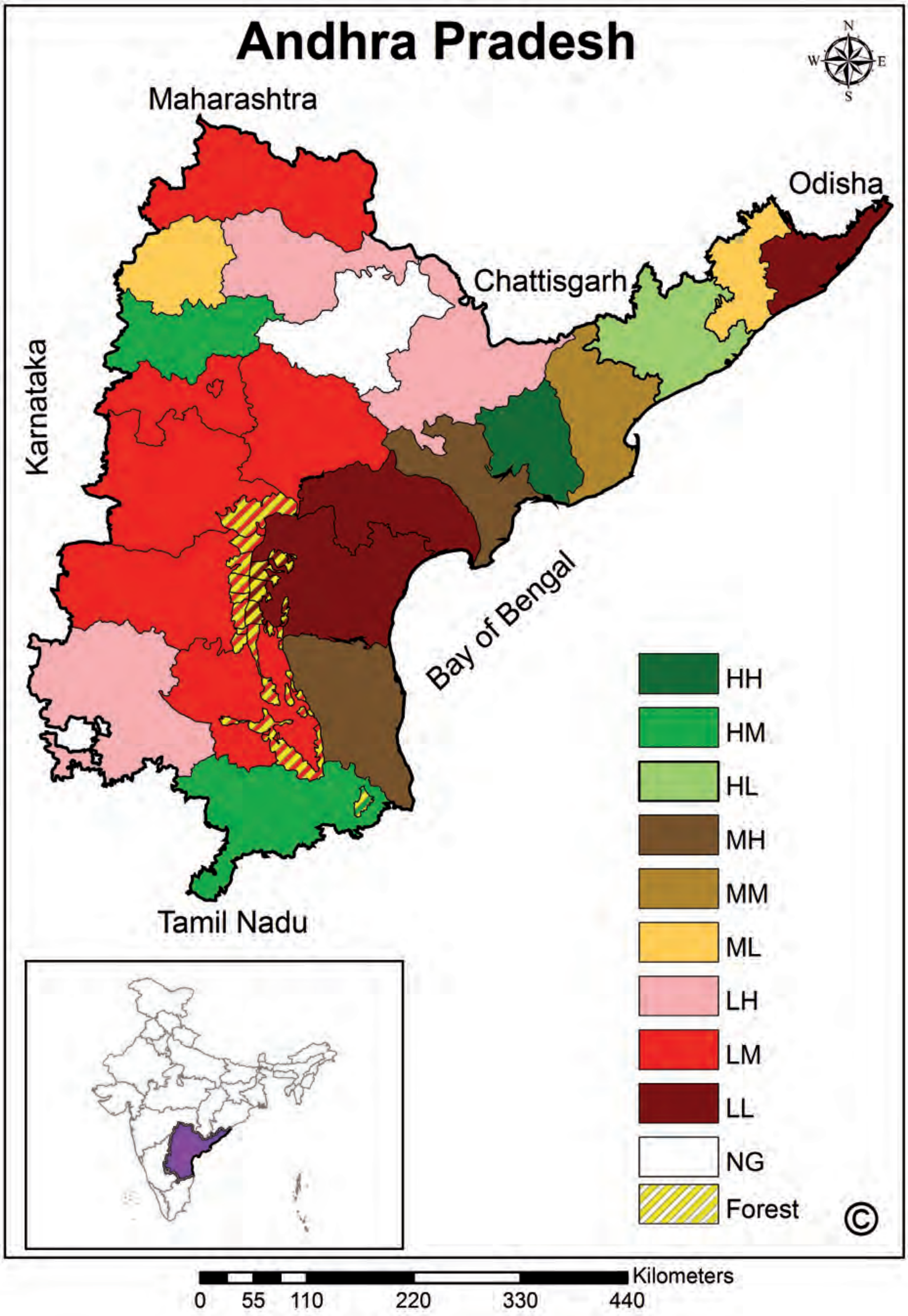

Fig. 51: Delineation of different productivity zones of sugarcane
(See text for abbreviation of legends)

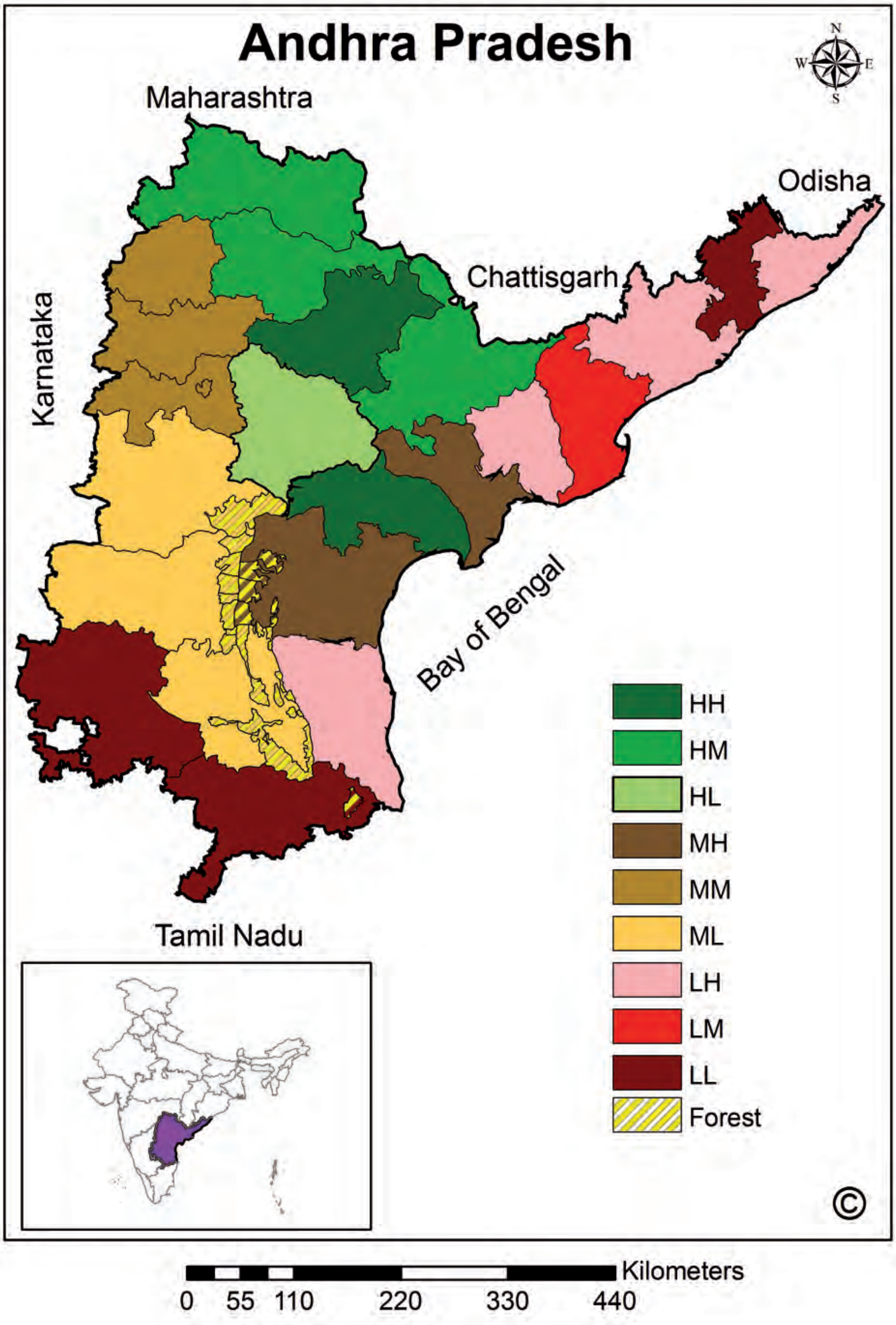

Fig. 52: Delineation of different productivity zones of cotton
(See text for abbreviation of legends)

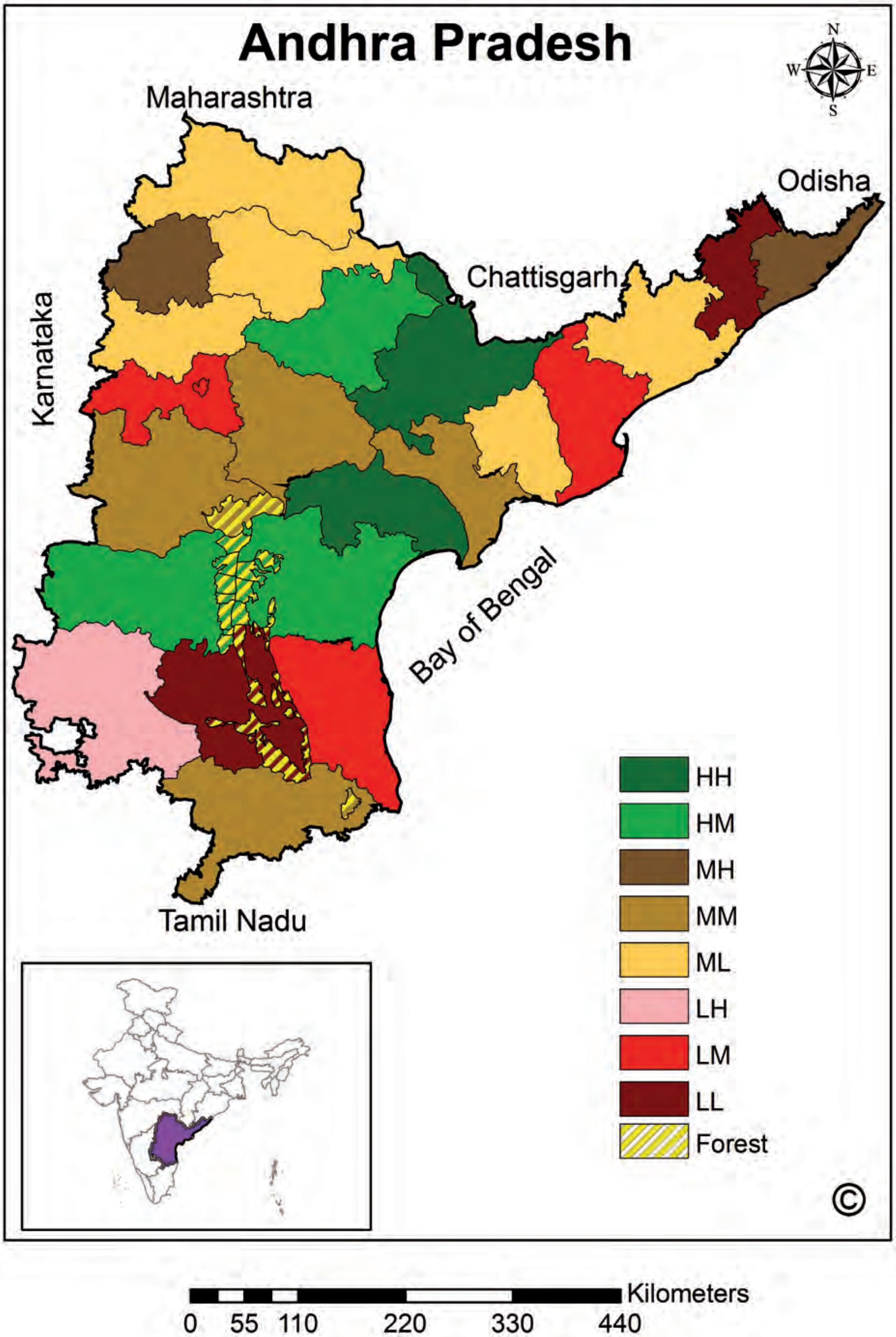

Fig. 53: Delineation of different productivity zones of chillies
(See text for abbreviation of legends)

3.7. Agrometeorological production constraints and opportunities for sustaining production of crops grown in Andhra Pradesh

3.7.1. Paddy

Delayed onset of monsoon is a common phenomenon in tankfed areas. This leads to transplanting of over-aged seedlings, and planting beyond optimum sowing time. This problem can be addressed by identifying areas with high probability of delayed monsoon. The promotion of short duration cultivars will be needed. In canal irrigated areas, late release of water occurs often times. It also leads to delayed planting with aged seedlings and in some years, entire *kharif* crop is lost. In case, the timing of water release dates can be forewarned using hydrological models coupled with seasonal forecast on monsoon, such losses can be minimized. Regarding the occurrence of pests and diseases, forewarning models need to be evolved on the incidence of sheath blight, blast, leaf folder, green leaf hopper, stem borer, gall midge. In years when monsoon is delayed, gall midge, stem borer, leaf folder and BPH in season when late release of water in canal irrigated system occurs. Floods are also a common feature in coastal agro-ecosystem and in low lying areas elsewhere. Prior information on the areas that are going to be inundated using basin models should help in saving the standing crop as well as harvested produce. Mapping of the areas prone to frequent floods with the help of historic rain data aids in designing, development and maintenance of appropriate drainage systems. Poor drainage condition and frequent flooding leads to development of salinity in paddy fields, which affects the standing paddy crop and succeeding paddy fallow pulse / maize crops. Models developed on the leaching requirement based on the rain data may assist in keeping the salinity at desirable levels in the root zone of the crop.

3.7.2. Cotton

Delayed as well as break monsoon conditions determine cotton productivity in majority of the growing areas. Region wise seasonal forecast on the behaviour of monsoon can help farmers in choice of appropriate cultivar and cropping systems. Advance information on the late arrival of monsoons could help in rescheduling of fertilizer application and application of soil conservation measures vigorously. Information on possible break monsoon conditions would also help in assessing the likely buildup of sucking pests in cotton. The development of decision support system for each pest would help to reducing the cost of cultivation. In some seasons, late withdrawal of monsoon creates physiological drought in cotton because of excess moisture. Advance information on this aspect would allow farmers to strengthen drainage facilities. High incidence of boll worm (or *spodoptera*) is likely under these situations and agromet advisories could help in the taking up prophylactic measures. Early withdrawal of monsoons in some years create nutrient deficiency in cotton. Any information on the impending early withdrawal could potentially help the farmers in rescheduling the fertilizer applications or resorting to foliar sprays. During high rainfall events and prolonged wet spells cotton is sensitive to high humidity and boll rot can occur; therefore prophylactic measures should be taken up if timely and precise agromet advisory system has been developed.

3.7.3. Pulses

Early information about the delayed onset of monsoons helps in the selection of cultivars suitable for reduced LGP. This information could also help the concerned agricultural departments, for the mobilization of inputs like seed, fertilizers etc., Information on the ensuing break monsoon conditions in pulse growing areas can assist in developing agromet advisories on intercultural operations, thinning out and adoption of soil moisture conservation practices. Nutrient deficiencies that develop due to mid-season droughts in pulses can be avoided / corrected through weather based decision support systems. In case of failure of monsoon in upland regions advisories on the selection of crops / cultivars and intercropping systems are highly useful. In case of prolonged delay in the onset of Southwest monsoon season, farmers resort to sowing of pulses on the receipt of rains late in the season. In such situations advisories on likely pest and disease incidence are crucial. For example, sowing of chickpea in the month of September exposes the crop to *sclerotium* collar rot.

3.7.4. Oilseeds

Delayed monsoon conditions severely affect productivity of oilseed crops particularly groundnut. Seasonal agromet advisories help in the process of selection of appropriate cultivars in groundnut and other oilseed crops. If onset of monsoon is delayed or sufficient rains are not received till July crops alternate to groundnut can be suggested, hence seasonal weather forecast is vital to minimize the losses at farm level. Break monsoon conditions create nutrient deficiency in oilseeds and early information on mid-season dry spell could assist the adoption of corrective measures for nutrient deficiencies. Advance information on heavy rains would allow time to the farmers to intensify measures to drain excess water, and early season forecasts on heavy rains could help in the formation of dead furrows at the time of sowing.

3.7.5. Sugarcane

Cane yields are affected to both deficit or excess of moisture and lack of rainfall during July and August results in a substantial reduction in cane yields. Trash mulching @ 3 t ha^{-1} during dry spells improves the cane yields. Like-wise if the crop is subjected to water logging the sucrose content in the cane reduces, thus affecting the recovery of sugar. High winds make the crop to lodge which depresses juice sucrose and cane weight decreases as well. All these field problems can be addressed by proper and timely agromet advisories.

3.7.6. Chillies

During break monsoon conditions a complex of sucking pest increasingly attack chillies and the crop undergoes nutrient and moisture stress. Issue of agromet advisories well in advance, would facilitate farmers to resort to intercultural operations to conserve soil moisture, and take-up foliar application of nutrients to correct any deficiency. If the monsoon rains are considerably delayed, then advisories on the methods of sowing and selection of cultivars to be planted will help to sustain the yield at appropriate levels.

4. Rainfall characteristics

Rain is the primary source of water and any deficit or excess of it during the crop growing season determines their productivity. Commencement and withdrawal of monsoons determines the length of growing period, choice of crop and their cultivars. It determines thereby yields of crops grown in about 42% rainfed area of the state. Not only the total quantity of rain during a crop season is important but also its distribution is vital to realize maximum yields.

4.1. Annual and seasonal rainfall

The mean annual and seasonal rainfall for the state for 22 districts (except Hyderabad district) is furnished in Table 6 and the spatial distribution is depicted in Fig. 54. The mean annual rainfall of Andhra Pradesh is 906 ± 176 mm with a coefficient of variation of 19% (Fig. 55). Andhra Pradesh is divided into three meteorological sub-divisions *viz.*, Coastal Andhra, *Telangana* and *Rayalaseema*. Annual rainfall is highest over coastal Andhra region (1019 mm), lowest over drought prone *Rayalaseema* region (699 mm) while it is intermediary over the *Telangana* region (866 mm). During the period 1971-2011, highest rainfall (1287 mm) was received in 2010 and lowest (647 mm) during 2002, this year incidentally was declared as an All-India drought year. There were six excess rainfall years (≥ 20 per cent above normal annual rainfall) and five deficit rainfall years (≤ 20 per cent less than normal annual rainfall). There is a large variability in rainfall across the districts with East Godavari topping the list (1125 mm) followed by Visakhapatnam (1114 mm) and Srikakulam (1106 mm) in the coastal Andhra region. In *Telangana* region, Khammam receives highest rainfall (1089 mm) followed by Adilabad (1046 mm). Lowest rainfall was noticed in Anantapur district (546 mm) which is the only arid district in the state. This is closely followed by Mahabubnagar (654 mm) and Kurnool (661 mm). The annual rainfall is highly variable in Nizamabad district followed by Karimnagar and Adilabad districts. Least variability in annual rainfall has been noticed in Vizianagaram district. The variability in the rainfall during SWM, was found to be highest in Anantapur district (36%) followed by SPSR Nellore (35%) and the least in Vizianagaram (17%). The mean variability during the NEM period is high in comparison to SW monsoon. Highest variability in NEM rainfall is observed in Nizamabad (95%) followed by Adilabad (94%) and a relative consistency in NEM was observed in SPSR Nellore (33%) followed by Chittoor (36%).

The rainfall in different seasons, as a percentage, of the total annual rainfall in the three regions of the state are presented in Table 7. SWM rainfall accounts for 67% of the annual on a state basis but in *Telangana* region this is 80% of the annual precipitation. Rainfall during NEM season is highest in *Rayalaseema*. Winter rains are negligible in the state however, sizeable summer rains are received in the *Rayalaseema* region.

4.2. Rainy days

A rainy day is defined as a day when cumulative rainfall received in a period of 24 hours is ≥ 2.5 mm. As a first approximation, the temporal distribution of rainfall can be understood from the number of rainy days. The mean annual rainfall of 906 mm is received over 47 rainy days with a variability of 15% (Table 8). Though the annual variability in rainy days is low, it is relatively high during monsoon season. This high variability reflects the frequency of intermittent dry spells during continuous wet spells. The number of rainy days in different seasons, as per cent, of the total annual rainy days in the three regions of the state are presented in Table 9. The number of rainy days closely follow the total rain received. Most of the rain events in coastal Andhra Pradesh occur during the SWM season.

On an annual basis, rain occurs more frequently over coastal Andhra region (52 days) than *Telangana* (46 days) and *Rayalaseema* regions (39 days). Number of rainy days are high in Visakhapatnam and Vizianagaram districts (58 days) followed by East Godavari (57 days) and lowest in Anantapur (32 days) followed by Kurnool and YSR Kadapa (38 days) districts (Fig. 56). An analysis of district-wise occurrences of rain events (Table 8) showed that for the state as a whole, the events are highly variable during the NEM season compared to SWM season. During the SWM season SPSR Nellore had registered highest variability (26%) followed by Anantapur (24%) district. Following the trends in variability in rainfall, Vizianagaram and Srikakulam districts registered least variability in the number of rainy days.

4.3. Features of SWM rainfall

Andhra Pradesh state receives 608 ± 177 mm rain during SWM season (Table 6). A study of rainfall pattern for the period 1971 to 2011 showed that the wettest SWM season occurred in 1988 (932 mm which is 53% above normal) and driest year is 2002 (410 mm which is 33 % less than normal). At the district level Adilabad receives highest amount of annual rainfall (904 mm) followed by Khammam (866 mm) and Nizamabad (823 mm). In the coastal region, West Godavari and Srikakulam districts receive high rainfall (725 mm) during SWM period (Fig. 57). Lowest rainfall is noticed in Anantapur district (322 mm) followed by SPSR Nellore (328 mm). Region-wise pattern of rainfall showed that *Telangana* region gets high rainfall (709 mm) and the least is in Ralayaseema (392 mm) while it is intermediary in the Coastal region (603 mm) on an average.

Andhra Pradesh state as a whole is subjected to 29 per cent variable monsoon rainfall. It is relatively high compared to All - India monsoon rainfall variability (11%) as well as variability for Southern Peninsular region (15%). Region-wise lowest variability is seen in coastal Andhra (26%) and highest in *Rayalaseema* (32%) and it is intermediate over *Telangana* (28%). At the district level, highest variability in the monsoon rainfall is observed in Anantapur district (36%) followed by SPSR Nellore (35%) and lowest in Vizianagaram (17%) and Srikakulam districts (20%) (Fig. 58).

On an average, SWM rainfall in the state is spread over 33 days. At the regional level highest number of rainy days are observed in the *Telangana* region (37 days) and lowest over the Ralayaseema region (22 days) and these are intermediate over the Coastal Andhra region (33 days). At the district level, Khammam and Adilabad districts recoded maximum number of rainy days (42 days) followed by Nizamabad (39 days) and these were least in Anantapur (18 days) and SPSR Nellore (20 days) (Fig. 59).

4.4. Features of NEM rainfall

Rainfall during NEM for the entire state is 214 ± 129 mm with a variability of 60%, which is almost two times more than the variability observed for the monsoon season rainfall. Highest NEM rainfall was observed in 1987 (381 mm - 78% above normal) and lowest in 1988 and 1989 (85 mm - 60% below normal). Coastal Andhra receives significant amount of rainfall (304 mm) mainly in the SPSR Nellore district. *Rayalaseema* receives a fairly good amount of rainfall (232 mm) and the lowest NEM rainfall is noticed in the *Telangana* region (116 mm).Thus, it can be inferred that chances of receiving rainfall over *Telangana* are relatively less. Among the districts, SPSR Nellore receives abundant rainfall (656 mm) during this season followed by Chittoor (376 mm) and it is lowest in Nizamabad (103 mm) and Adilabad (93 mm) districts (Fig. 60).

Variability in NEM rainfall is low over *Rayalaseema* region (44%) compared to the coastal Andhra (49%) and the *Telangana* region (73%). In Nizamabad district, the NEM rain is highly variable (95%) followed by Adilabad district (94%) and it is lowest in SPSR Nellore district (33%) followed by Chittor (36%) (Fig. 61).

Average number of rainy days during NEM season for the state is 10. However, it ranges from 5 days in Adilabad, Nizamabad, Karimnagar to 21 days days in SPSR Nellore (Fig. 62). Only the southern districts of the state experience a relatively strong NEM season.

4.5. Features of summer and winter rainfall

The mean summer rainfall for the state is 71 ± 31 mm. Wettest summer is 1990 (309 mm) and driest in 2000 (4 mm). At the regional level, Coastal Andhra get more rainfall (93 mm) than Ralayaseema (69 mm) and *Telangana* region (50 mm). Coastal districts Vizianagaram (152 mm), Visakhapatnam (143 mm) and Srikakulam (114 mm) receive high rainfall whereas the lowest is in Adilabad (34 mm) in *Telangana* region (Fig. 63). Rainfall during later part of this season in coastal districts is termed locally as pre-monsoon showers and can be attributed to development of convective clouds during evening hours in areas proximate to the sea. The summer season rainfall over the state is spread over only 4 rainy days but among the districts it ranged from four to eight (Table 8).

Rain during winter season is very meagre / insignificant and on an average the state receives 13 mm only. Thus, the winter season can be called as the driest. The winter of 2008 was the wettest (42 mm) and the year 2009 being the driest with no rainfall. Highest rainfall is received in coastal districts Vizianagaram (34 mm) in the north and SPSR Nellore (24 mm) in the south and in *Rayalaseema* it is paltry (Anantapur - 2.6 mm; YSR Kadapa - 3.8 mm) (Fig. 64).

4.6. Monthly rainfall and distribution of rainy days

Information on the monthly rainfall for a location is helpful for crop planning, cultivar selection, run off estimation, determining crop water needs, and for designing watersheds and ultimately irrigation system. The rainfall distribution on monthly basis with the associated variability for the state as well as for the districts is presented in Table 10. August is the wettest month in the state (181 mm) followed by July (167 mm), September (152 mm) and October (136 mm) in that order (Fig. 65). Albeit, highest rainfall is received during August, rainfall during September is associated with least variability (16%) indicating its consistency. At the district level also August rainfall is dominant in 11 out of 22 districts (Adilabad, East Godavari, Guntur, Khammam, Krishna, Mahabubnagar, Medak, Nalgonda, Nizamabad, Ranga Reddy and West Godavari), whilst September rainfall is dominant in Anantapur, Kurnool, Srikakulam, and Vizianagaram districts and October for Chittoor, Kadapa, Prakasam and Vishakapatnam districts, July rainfall is dominant in Karimnagar and Warangal districts (Fig. 66 a to l). On the contrary, SPSR Nellore district receives highest rainfall during November (292 mm) and this lone district in the state, has the distinction of receiving highest share in the annual rain of the NEM rainfall.

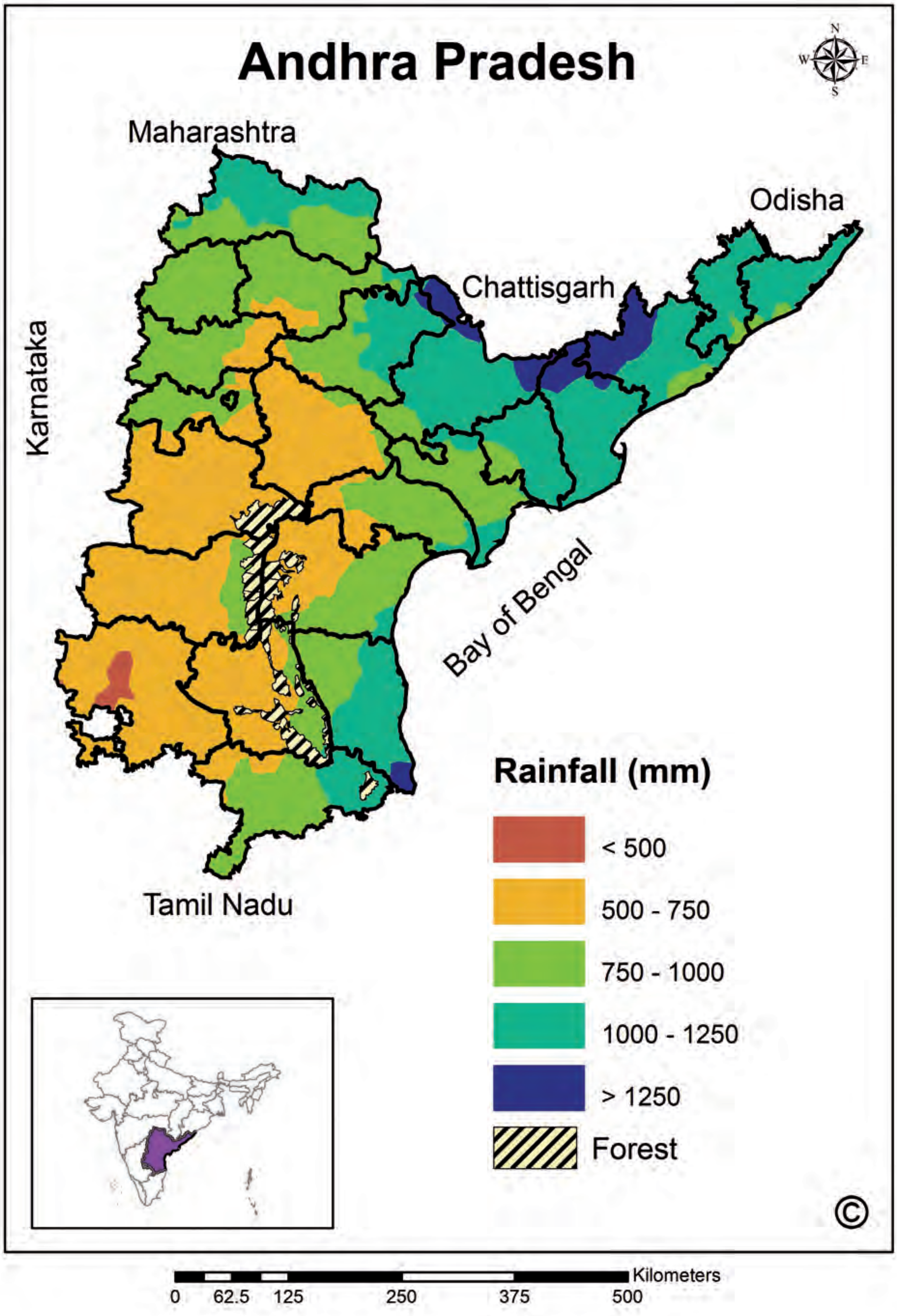

Fig. 54: Annual rain (mm) over Andhra Pradesh

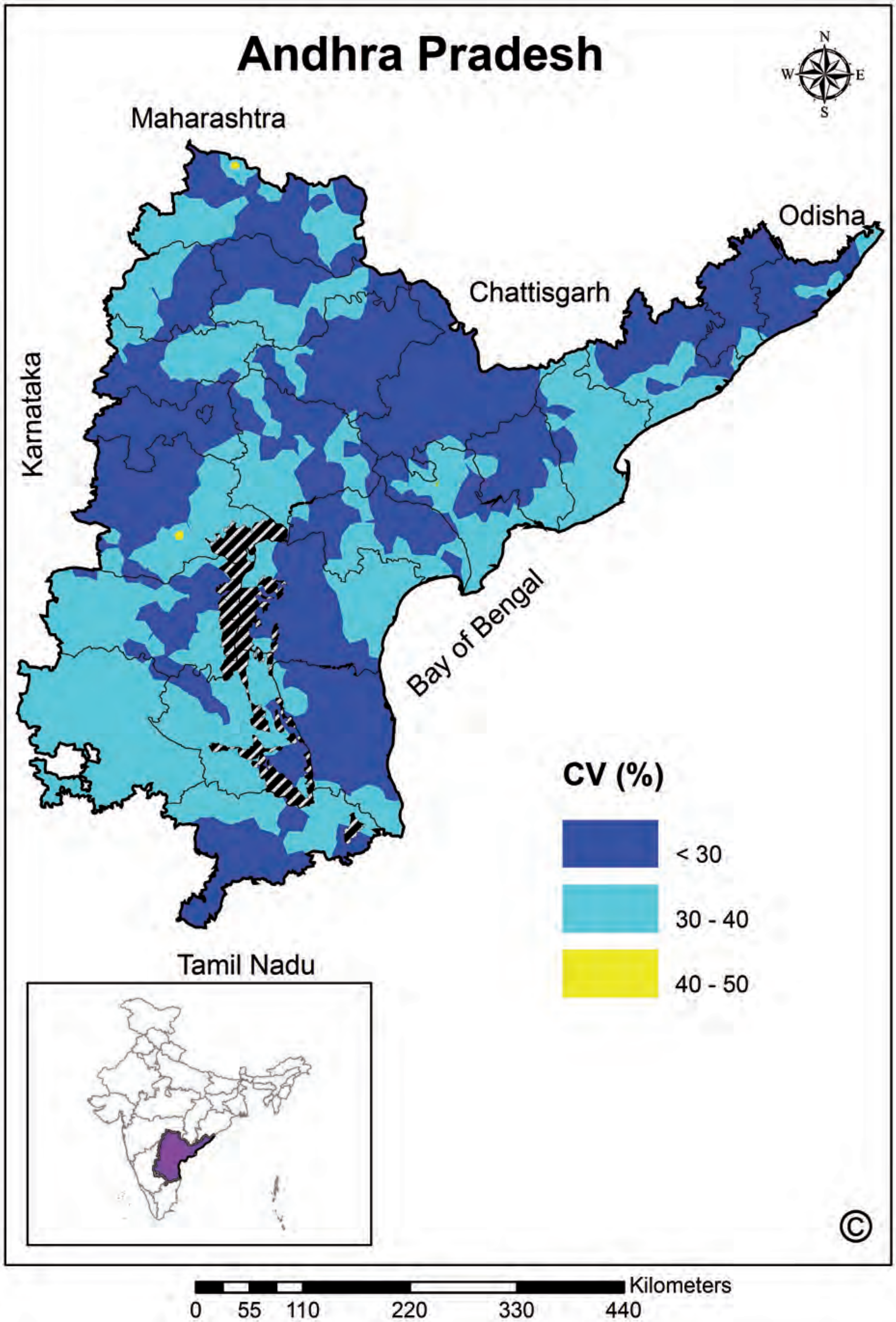

Fig. 55: Spatial variability (CV%) of annual rain in Andhra Pradesh

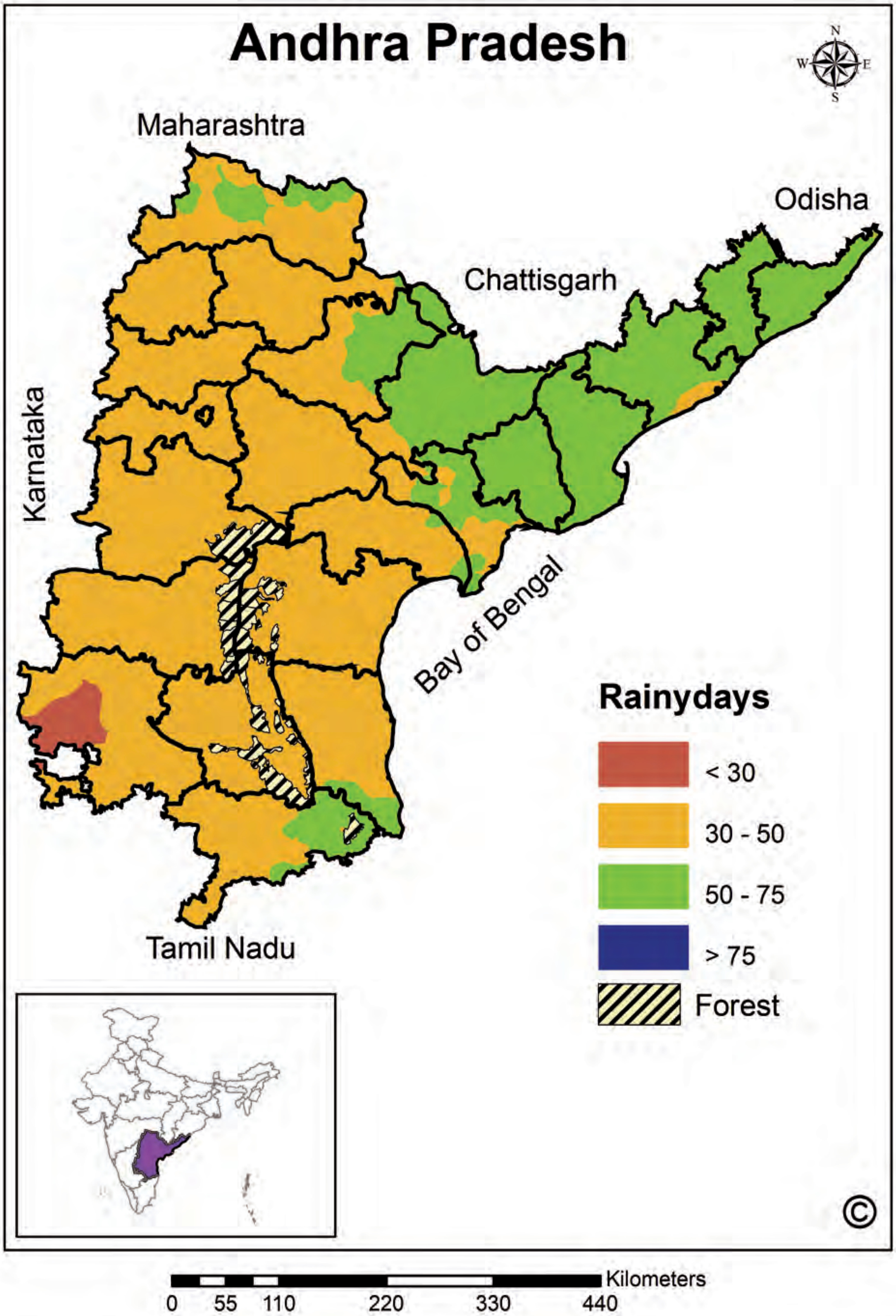

Fig. 56: Annual number of rainy days in Andhra Pradesh

Table 6: District wise mean annual and seasonal rainfall (mm) with its standard deviation (mm) and coefficient of variation (%)

District	Annual			Southwest Monsoon			Northeast Monsoon			Summer			Winter		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
Adilabad	1046	275	26	904	252	28	93	87	94	34	26	77	16	24	152
Anantapur	546	128	23	322	117	36	154	65	42	68	37	55	3	5	173
Chitoor	895	189	21	417	111	27	376	134	36	89	48	54	13	23	185
YSR Kadapa	693	153	22	382	124	32	249	97	39	58	34	59	4	8	199
East Godavari	1126	257	23	711	168	24	301	150	50	96	110	114	17	20	120
Guntur	849	180	21	548	159	29	227	106	47	63	66	105	12	17	140
Karimnagar	926	241	26	761	229	30	104	84	81	45	32	72	17	24	142
Khammam	1089	235	22	866	219	25	137	75	55	75	67	90	13	14	106
Krishna	973	231	24	656	204	31	237	114	48	67	76	113	12	16	127
Kurnool	661	150	23	446	138	31	147	85	58	63	29	45	4	5	128
Mahabubnagar	654	146	22	480	138	29	116	77	66	53	40	76	5	7	139
Medak	820	213	26	653	195	30	107	83	77	50	41	82	9	17	181
Nalgonda	712	164	23	520	147	28	139	89	64	44	42	95	9	13	144
SPSR Nellore	1069	252	24	328	116	35	656	218	33	62	71	115	24	47	191
Nizamabad	979	287	29	823	258	31	103	98	95	39	34	88	14	24	176
Prakasam	802	175	22	382	126	33	340	129	38	65	64	99	15	19	130
Ranga Reddy	789	172	22	598	156	26	121	79	66	61	44	72	8	11	138
Srikakulam	1106	224	20	725	145	20	247	153	62	114	98	86	20	24	120
Visakhapatnam	1114	252	23	688	140	20	266	142	53	143	134	94	18	23	129
Vizianagaram	1078	204	19	666	116	17	226	126	56	152	108	71	34	29	84
Warangal	960	203	21	773	210	27	122	76	63	52	43	84	13	20	150
West Godavari	1052	241	23	725	203	28	237	114	48	78	92	119	12	17	135
State	**906**	**176**	**19**	**608**	**177**	**29**	**214**	**129**	**60**	**71**	**31**	**44**	**13**	**7**	**54**

Table 7: Annual rainfall distribution in different regions and rainfall in different seasons as per cent of annual

Region	Rainfall (mm)					% of annual rainfall			
	Annual	Northeast	Southwest	Summer	Winter	Northeast	Southwest	Summer	Winter
Telangana	886	116	709	50	11	13	80	6	1
Rayalaseema	699	232	392	69	6	33	56	10	1
Coastal Andhra	1019	304	603	93	18	30	59	9	2
State	**906**	**214**	**608**	**71**	**13**	**24**	**67**	**8**	**1**

Table 9: Region-wise and season-wise distribution of annual rainy days and as per cent of annual

Region	Rainy days					% of annual rainy days			
	Annual	Northeast	Southwest	Summer	Winter	Northeast	Southwest	Summer	Winter
Telangana	46	6	37	3	1	13	79	7	2
Rayalaseema	39	12	22	4	0	31	58	11	1
Coastal Andhra	52	13	33	5	1	24	65	9	2
State	**47**	**10**	**33**	**4**	**1**	**21**	**70**	**9**	**2**

Table 8: District wise mean annual and seasonal rainy days with its standard deviation and coefficient of variation (%)

District	Annual			Southwest			Northeast			Summer			Winter		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
Adilabad	50	7	14	42	7	16	5	3	58	2	2	61	1	1	119
Anantapur	32	6	18	18	4	24	9	3	35	4	2	49	0	0	161
Chitoor	47	7	15	24	5	21	18	5	27	5	2	46	1	1	141
YSR Kadapa	38	6	16	21	5	23	13	4	28	3	2	52	0	0	172
East Godavari	57	8	14	39	6	16	12	4	33	5	2	51	1	1	101
Guntur	45	6	14	30	6	18	11	4	32	3	2	65	1	1	117
Karimnagar	47	8	16	38	7	19	5	3	58	3	2	55	1	1	129
Khammam	54	7	13	42	7	15	7	3	43	4	2	50	1	1	100
Krishna	50	8	15	35	6	18	11	4	33	3	2	66	1	1	113
Kurnool	38	6	15	26	5	20	8	3	40	4	2	39	0	0	116
Mahabubnagar	39	7	18	29	6	20	6	3	49	3	2	57	0	0	118
Medak	45	8	18	35	7	19	6	3	55	3	2	60	1	1	152
Nalgonda	39	7	18	29	6	19	7	3	48	2	2	72	1	1	113
SPSR Nellore	45	7	16	20	5	26	21	6	26	2	2	75	1	1	138
Nizamabad	49	8	18	40	7	18	5	3	64	3	2	63	1	1	133
Prakasam	42	6	14	24	5	21	14	4	29	3	2	68	1	1	119
Ranga Reddy	46	8	17	35	6	18	7	3	48	4	2	46	1	1	136
Srikakulam	55	8	14	38	5	13	10	5	47	6	3	52	1	1	104
Visakhapatnam	58	9	15	38	5	14	11	5	40	8	4	50	1	1	105
Vizianagaram	58	7	13	38	5	13	10	4	43	8	3	40	2	2	76
Warangal	48	7	15	38	7	17	7	3	44	3	2	61	1	1	130
West Godavari	54	8	15	38	6	16	11	4	35	4	3	72	1	1	122
State	**47**	**7**	**15**	**33**	**8**	**23**	**10**	**4**	**44**	**4**	**2**	**40**	**1**	**0**	**51**

Table 10: Average monthly rainfall in different districts of Andhra Pradesh

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adilabad	10	6	8	10	16	173	286	298	147	77	13	3
Anantapur	1	2	7	13	47	55	60	80	127	109	38	7
Chitoor	5	8	10	20	59	69	97	110	141	168	147	61
YSR Kadapa	1	3	6	11	40	62	89	108	123	140	87	22
East Godavari	6	11	12	21	63	131	187	205	188	199	87	14
Guntur	4	8	9	14	40	90	144	160	154	139	74	15
Karimnagar	10	7	12	14	19	140	240	237	144	82	18	4
Khammam	6	7	11	18	45	145	274	279	168	107	24	6
Krishna	5	8	11	13	43	111	186	199	161	157	66	14
Kurnool	2	2	7	16	41	83	102	126	135	116	27	5
Mahabubnagar	2	3	9	14	30	82	125	141	131	93	20	3
Medak	6	3	12	15	23	118	189	204	142	87	18	3
Nalgonda	4	5	9	11	24	92	137	152	139	105	32	3
SPSR Nellore	13	12	7	12	43	48	81	92	107	273	292	90
Nizamabad	9	5	11	10	19	149	247	278	150	84	16	3
Prakasam	7	8	11	12	42	62	88	104	127	189	128	24
Ranga Reddy	4	4	12	18	31	108	160	181	150	100	19	2
Srikakulam	5	14	17	27	70	143	177	202	203	180	60	7
Visakhapatnam	6	12	17	40	86	140	172	186	190	192	65	9
Vizianagaram	14	20	27	42	83	136	168	175	187	145	65	16
Warangal	7	7	12	13	26	135	254	233	151	95	22	5
West Godavari	5	7	11	16	50	122	204	228	171	164	61	11
State	**6**	**7**	**11**	**17**	**43**	**109**	**167**	**181**	**152**	**136**	**63**	**15**
Stan. dev	**4**	**4**	**4**	**9**	**20**	**36**	**66**	**63**	**24**	**50**	**63**	**21**
CV	**59**	**60**	**40**	**50**	**46**	**33**	**39**	**35**	**16**	**37**	**101**	**142**

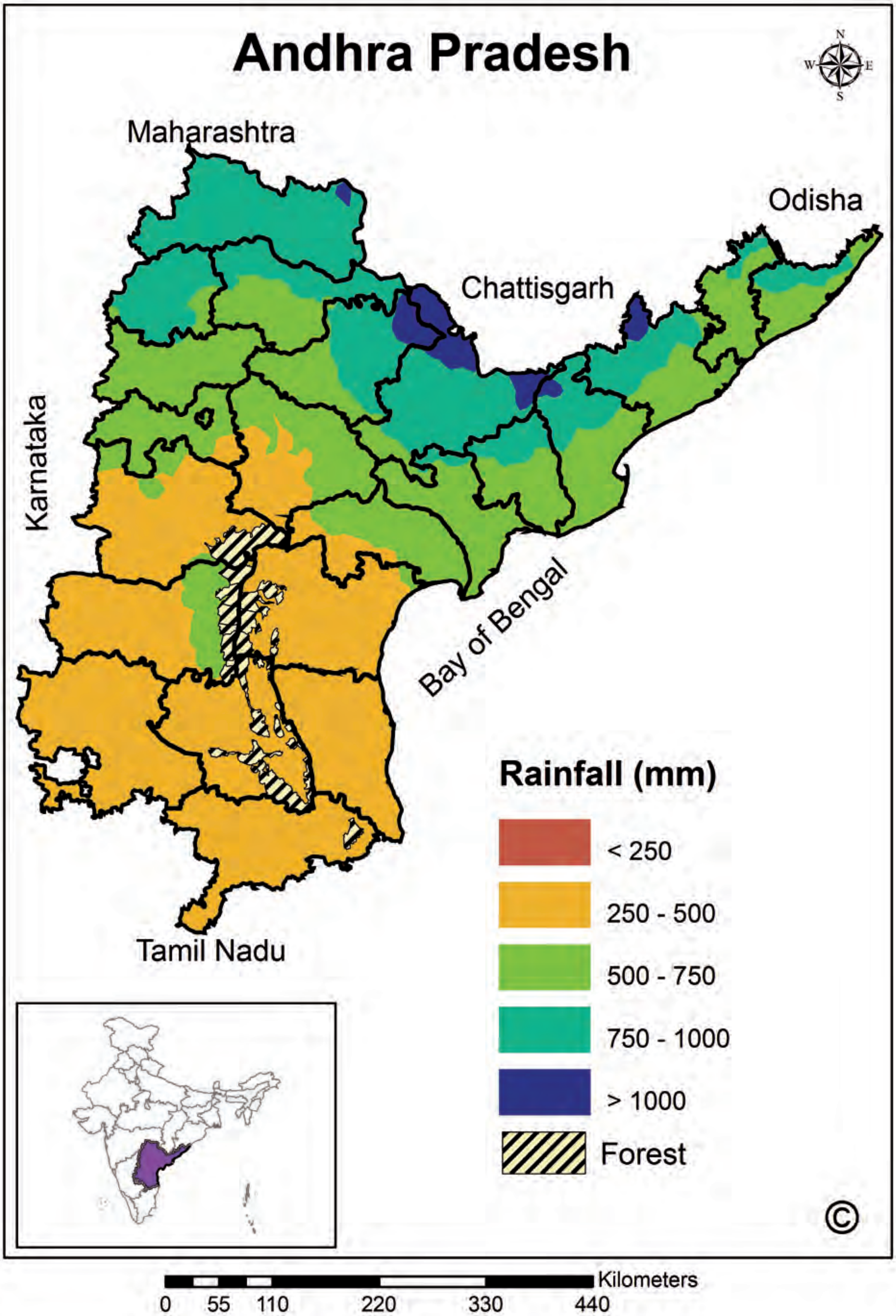

Fig. 57: Southwest monsoon rain (mm) over Andhra Pradesh

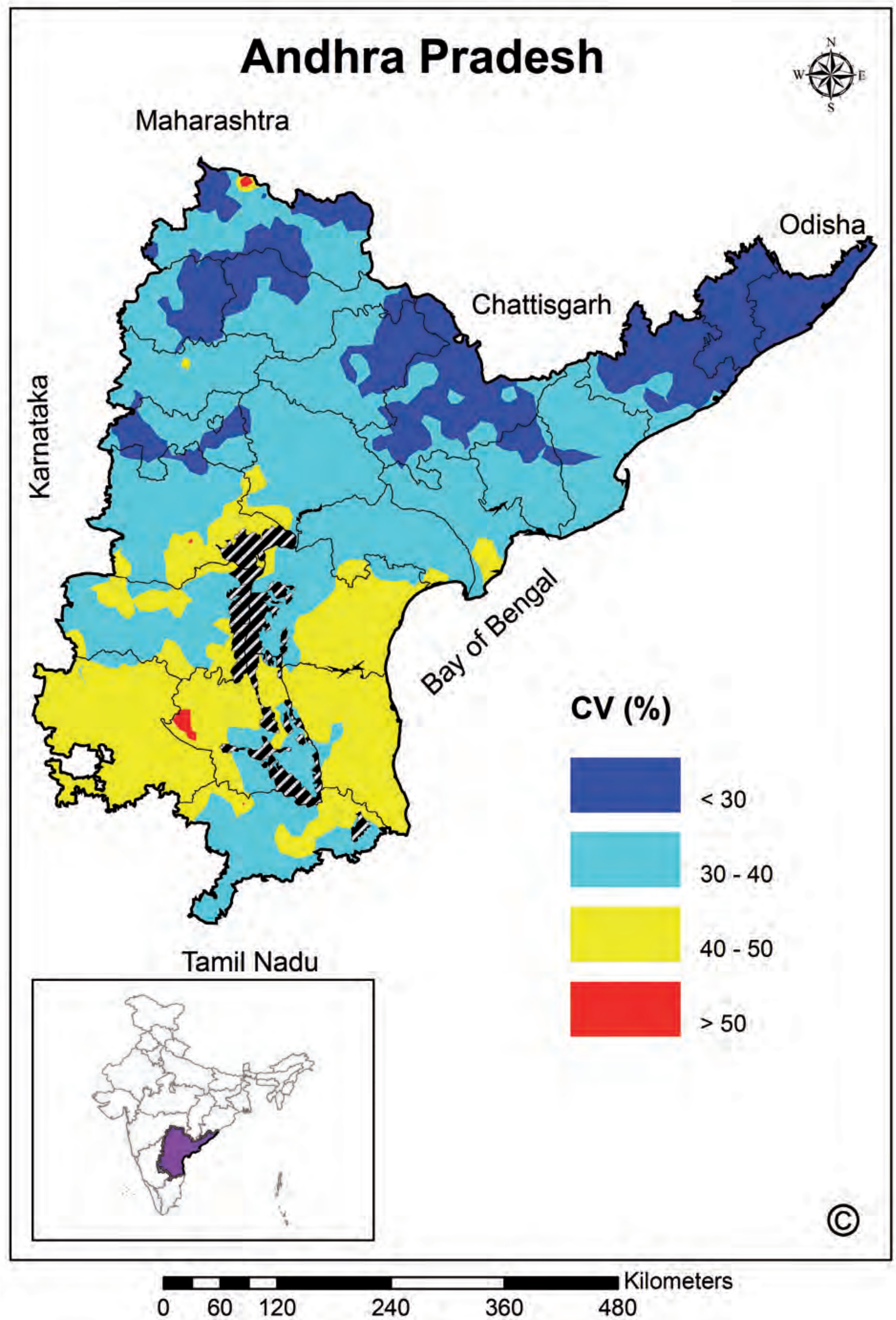

Fig. 58: Variability (CV %) in Southwest monsoon rainfall over Andhra Pradesh

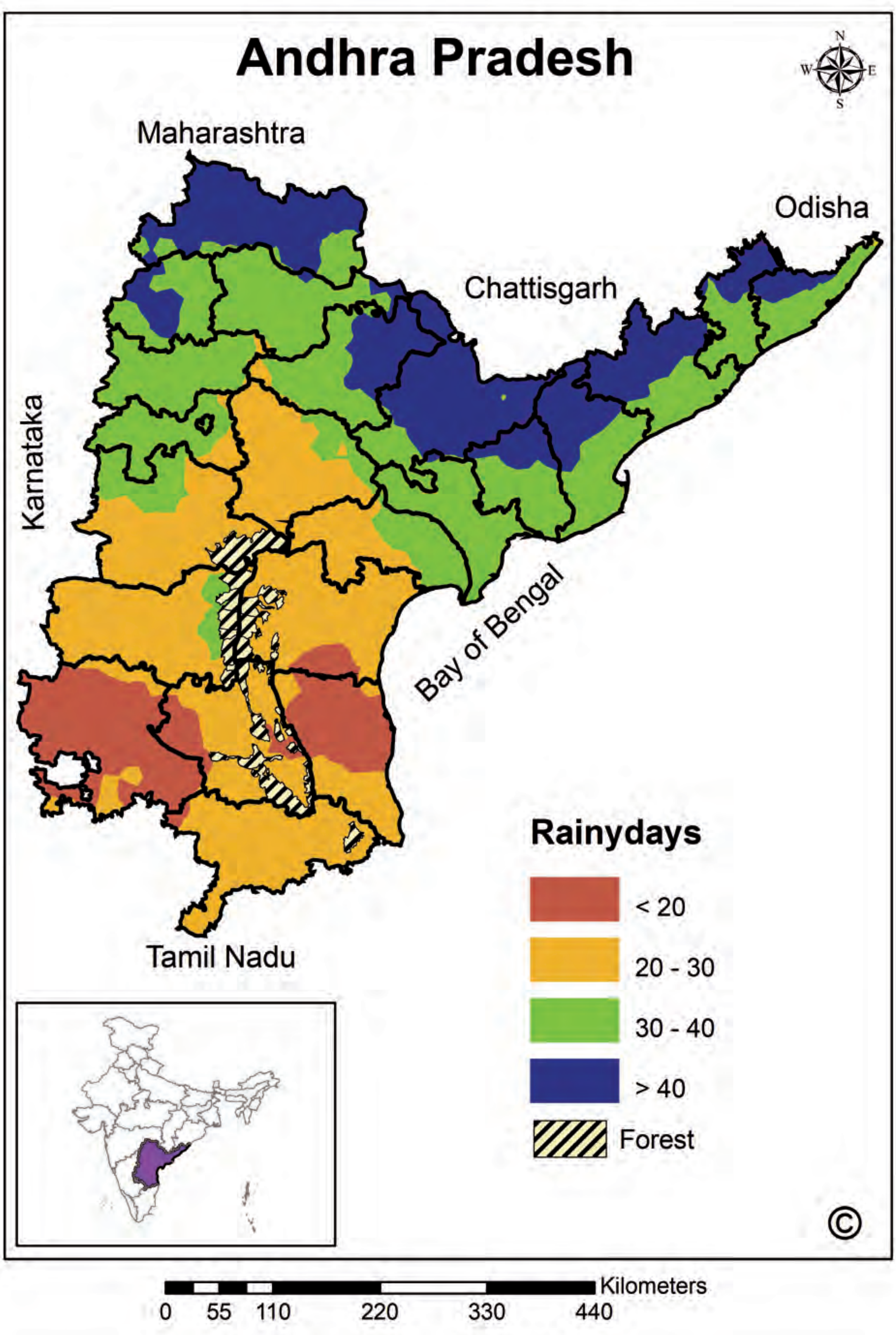

Fig. 59: Number of rainy days during Southwest monsoon season over Andhra Pradesh

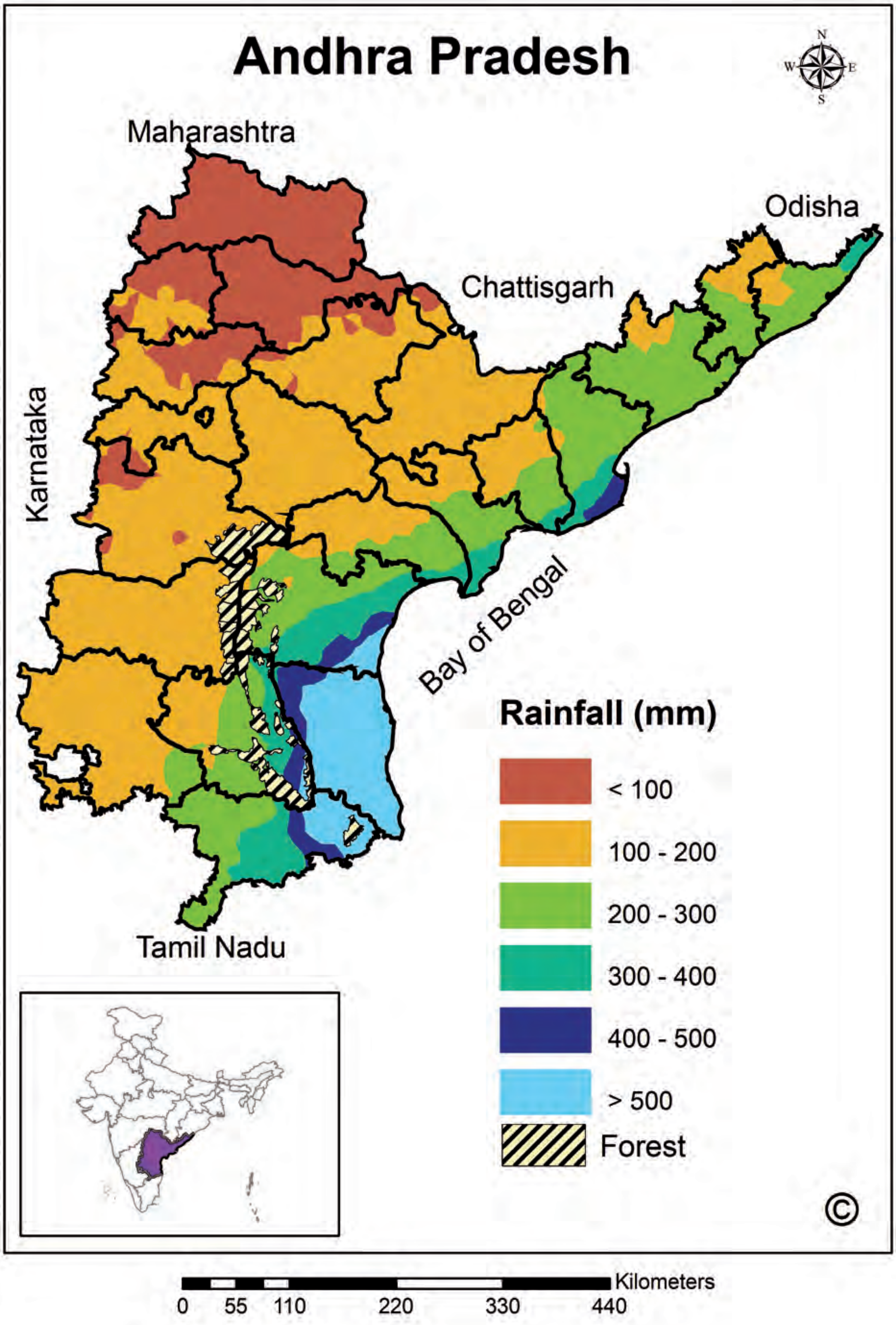

Fig. 60: Northeast monsoon rainfall (mm) over Andhra Pradesh

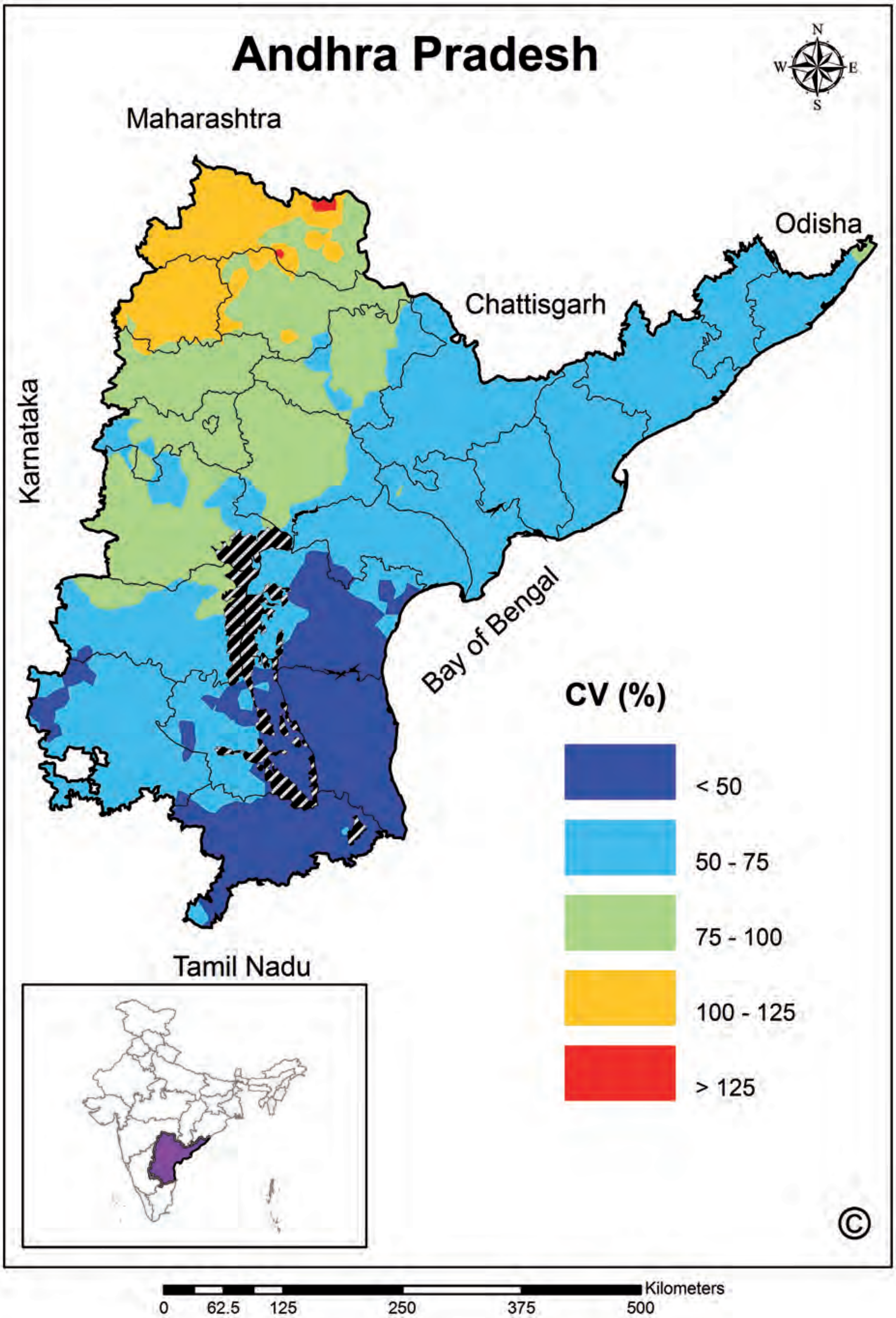

Fig. 61: Variability (CV %) in Northeast monsoon rainfall over Andhra Pradesh

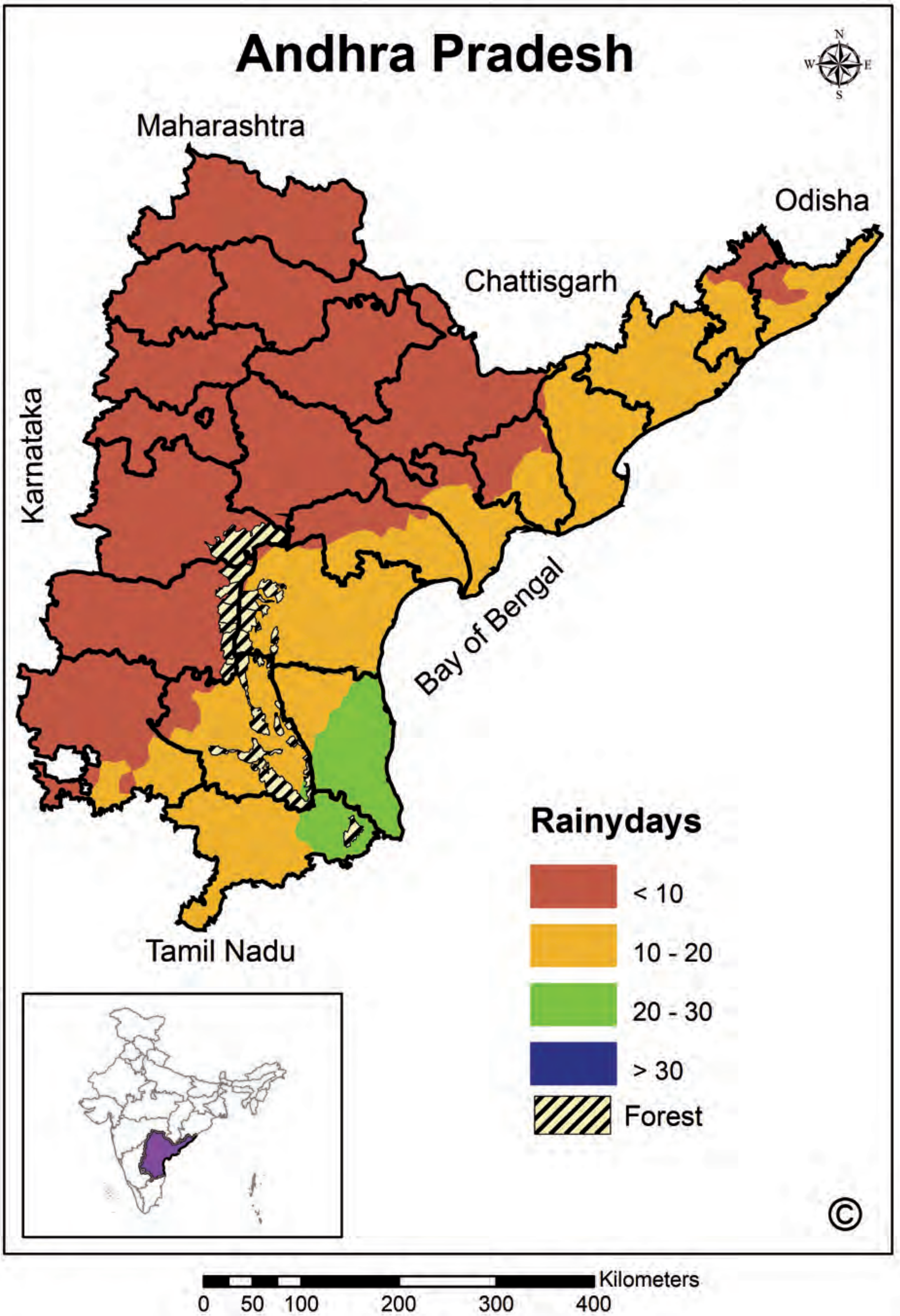

Fig. 62: Number of rainy days during Northeast monsoon season over Andhra Pradesh

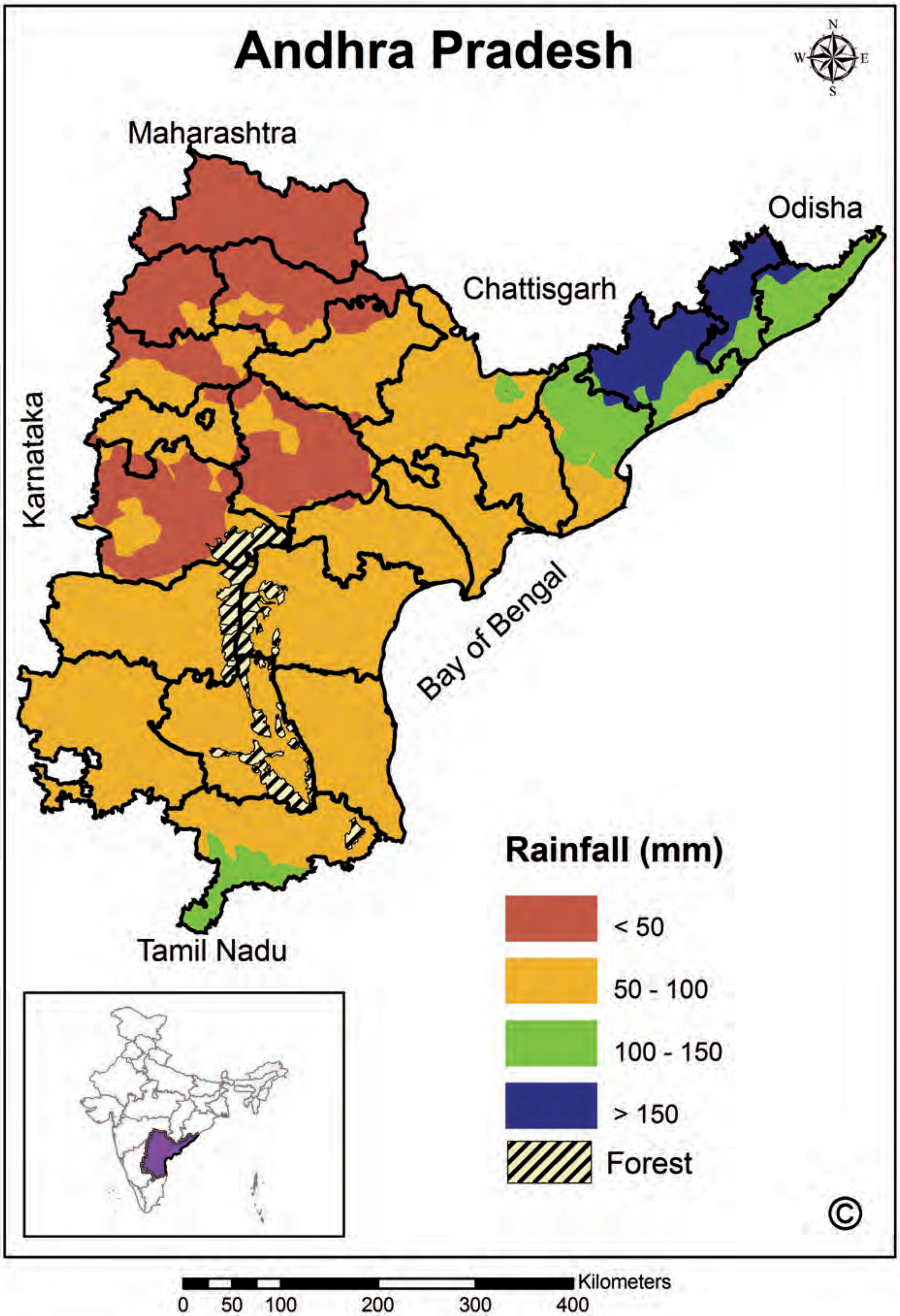

Fig. 63: Summer season rain (mm) over Andhra Pradesh

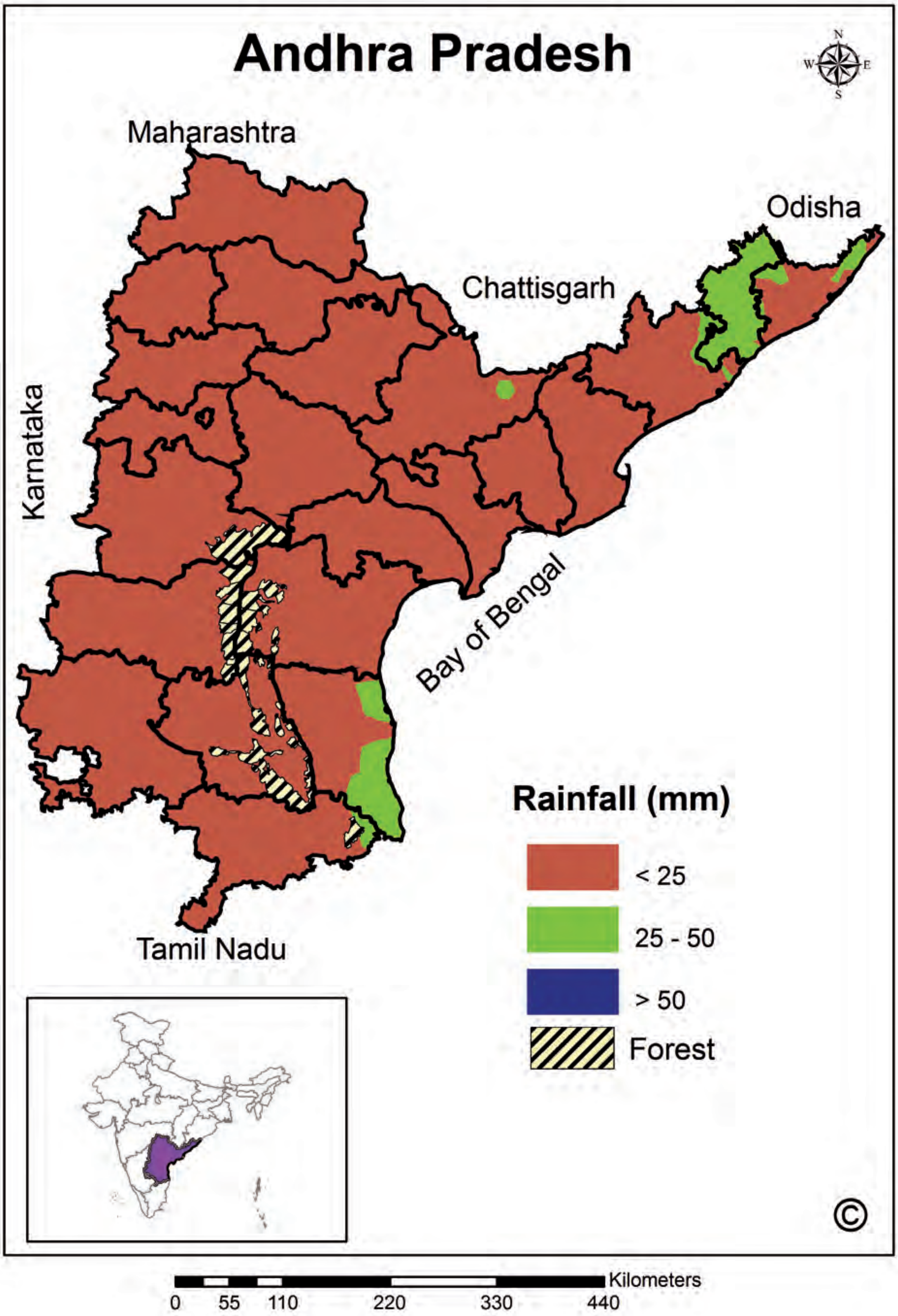

Fig. 64: Winter season rain (mm) over Andhra Pradesh

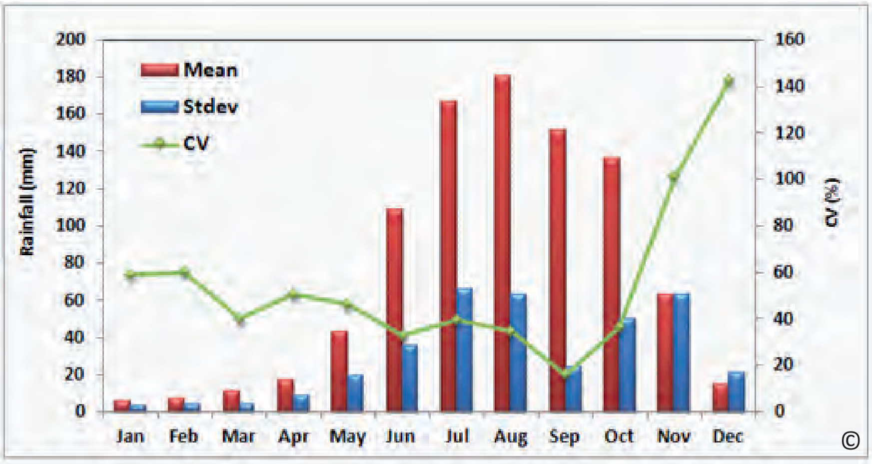

Fig. 65: Average monthly rain for Andhra Pradesh

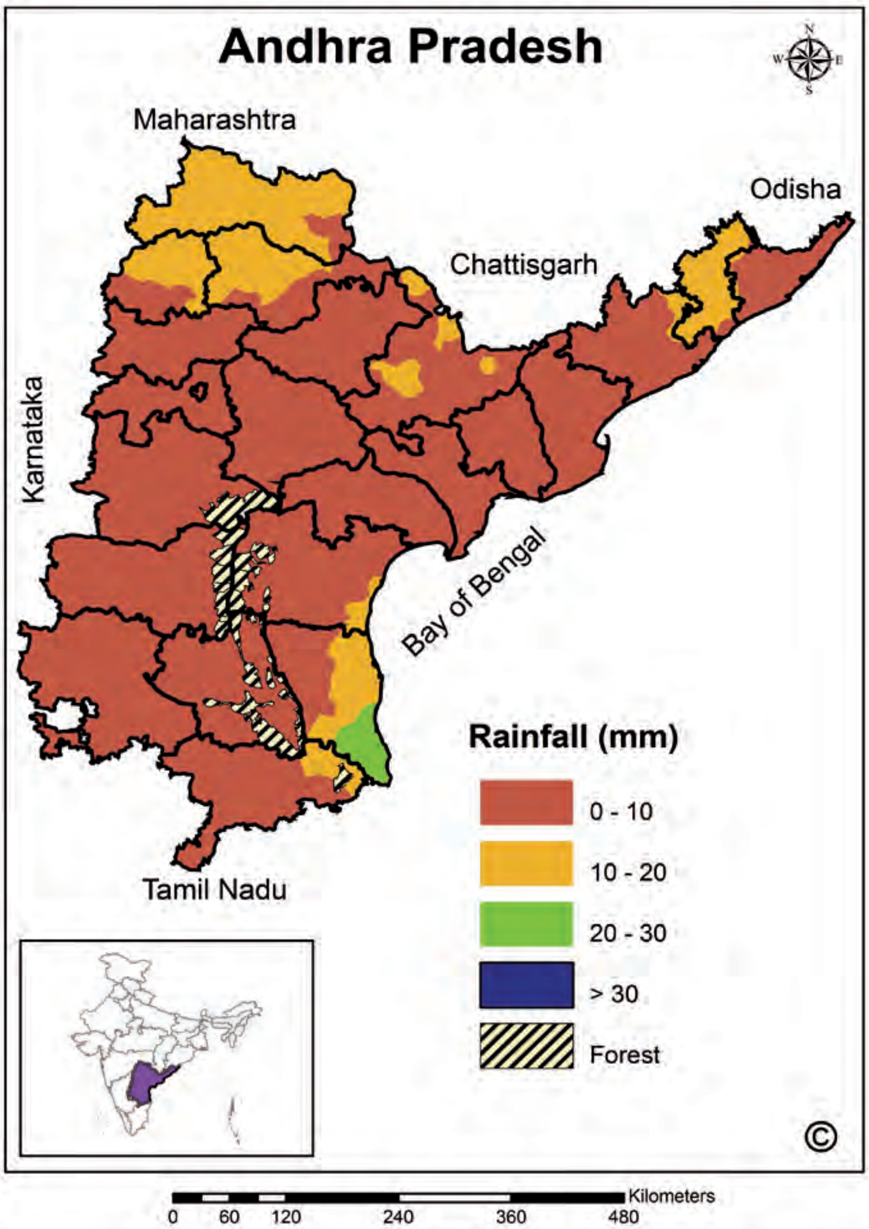

Fig. 66 a: Rain in January in Andhra Pradesh

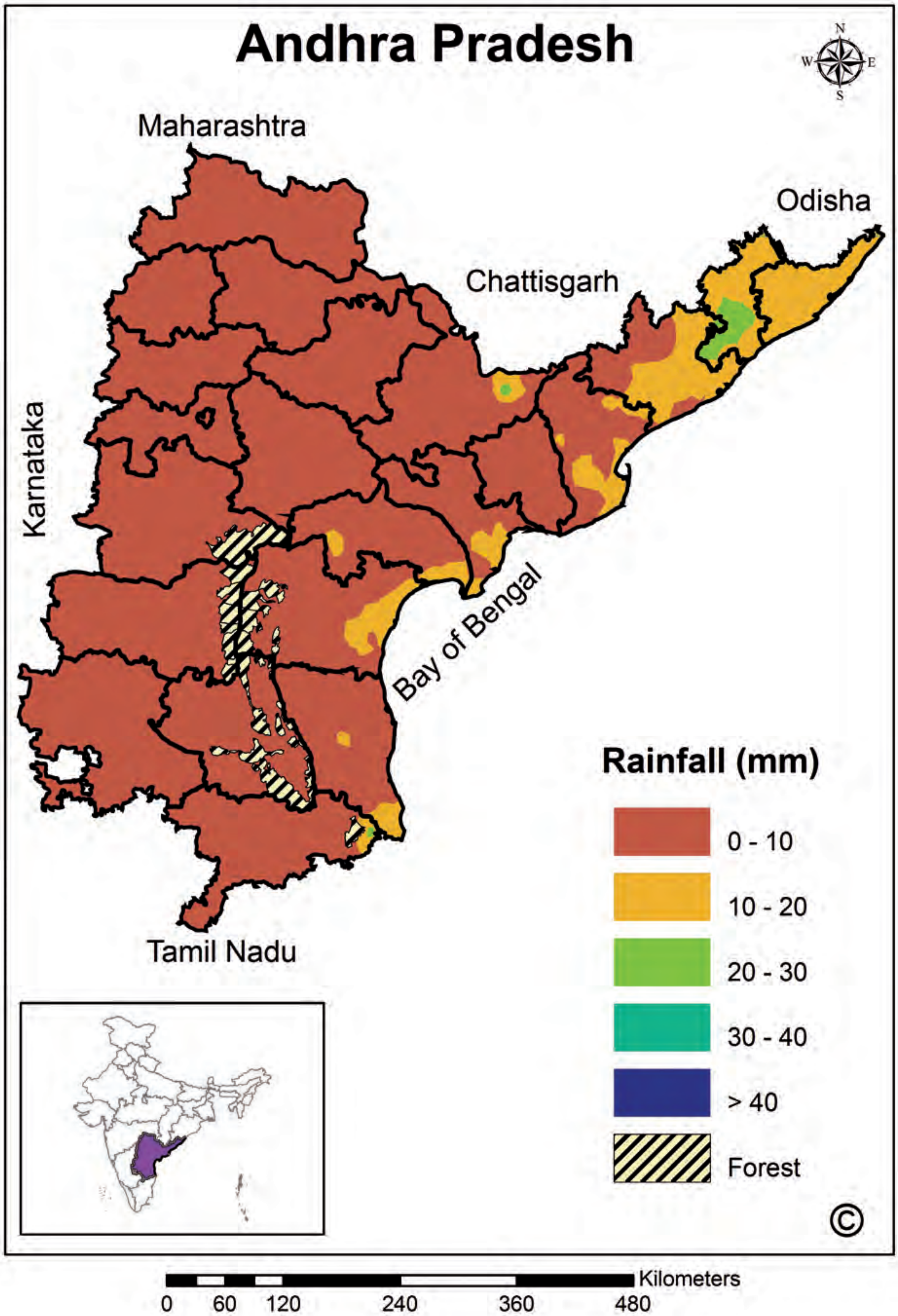

Fig. 66 b: Rain in February in Andhra Pradesh

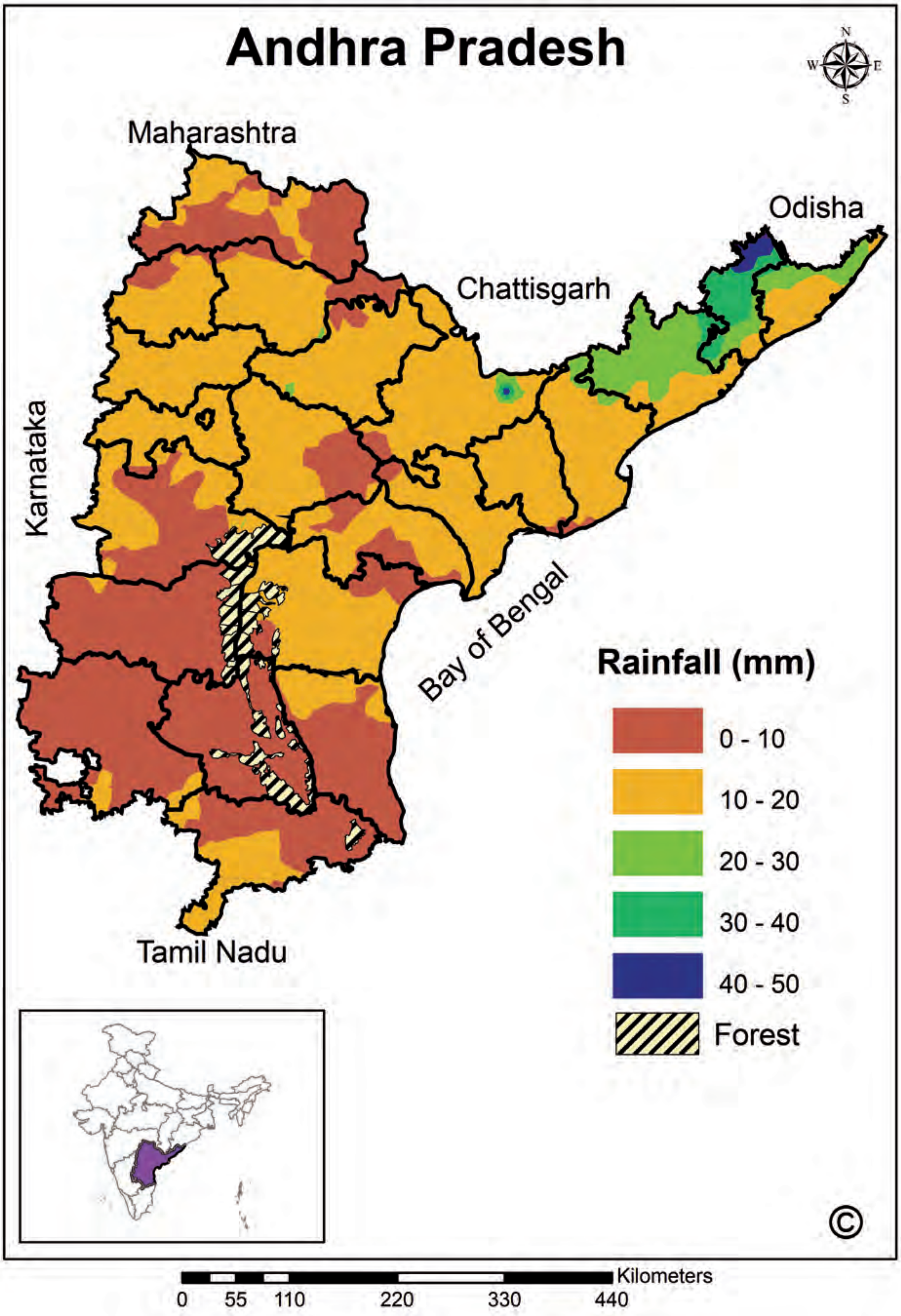

Fig. 66 c: Rain in March in Andhra Pradesh

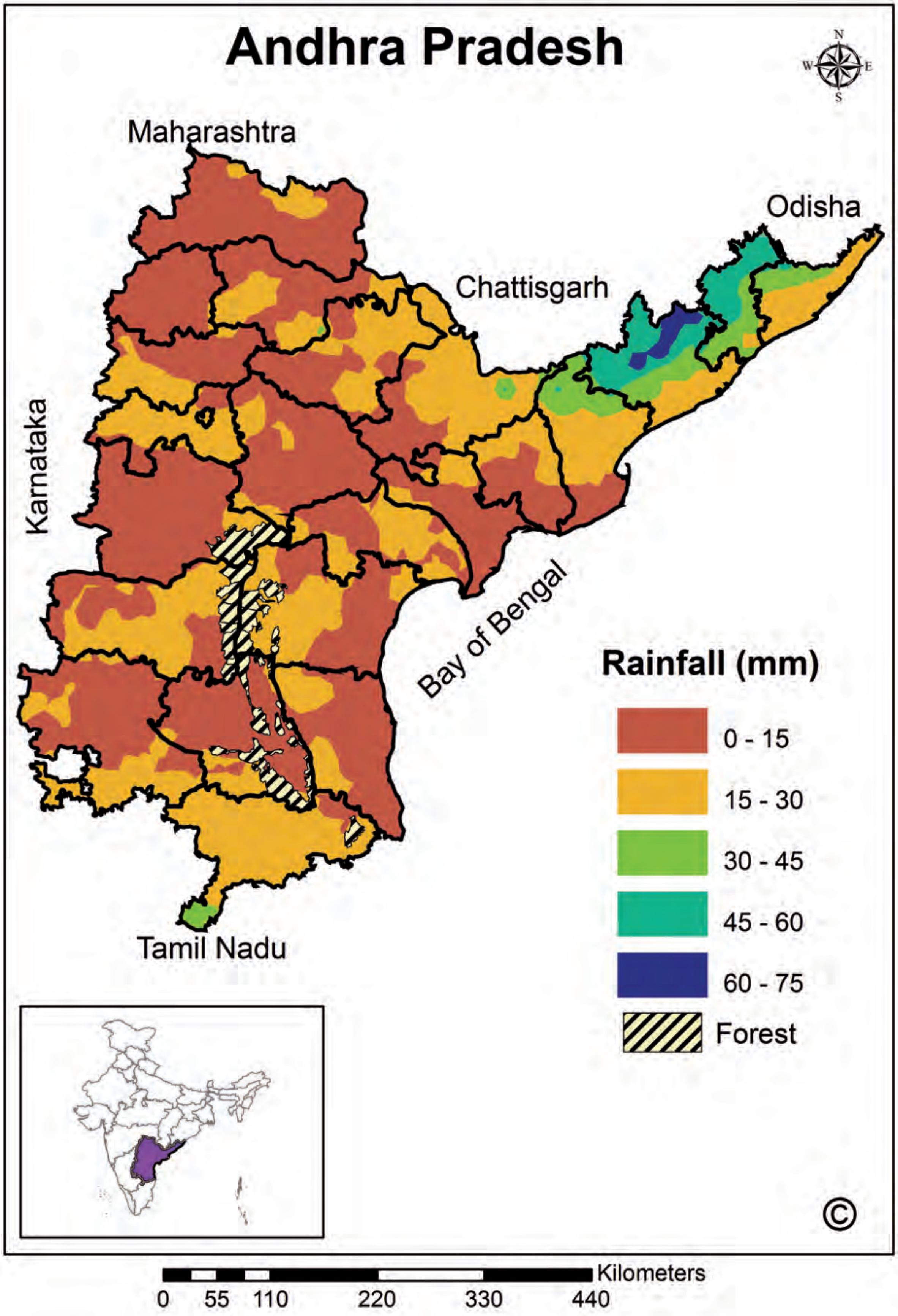

Fig. 66 d: Rain in April in Andhra Pradesh

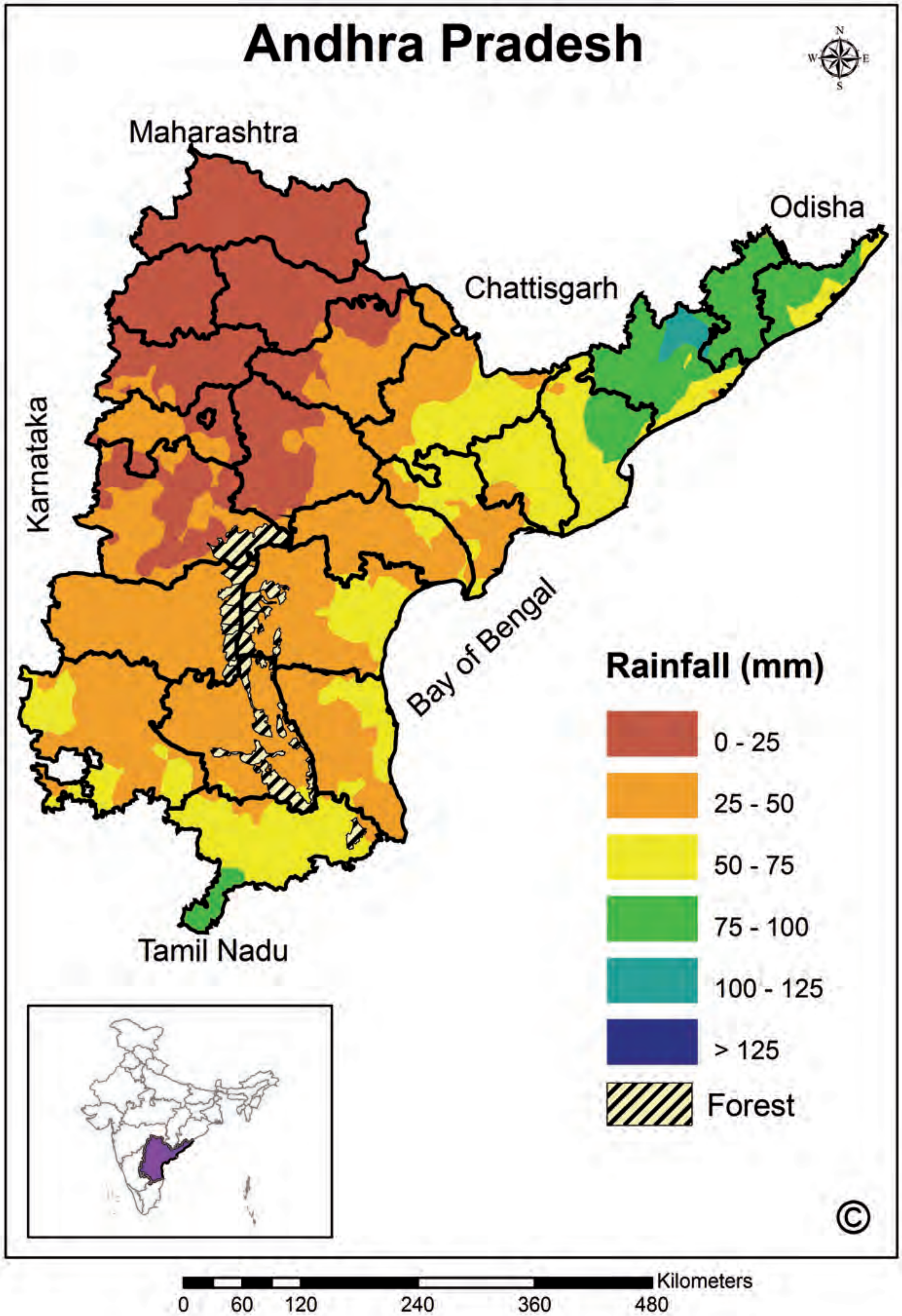

Fig. 66 e: Rain in May in Andhra Pradesh

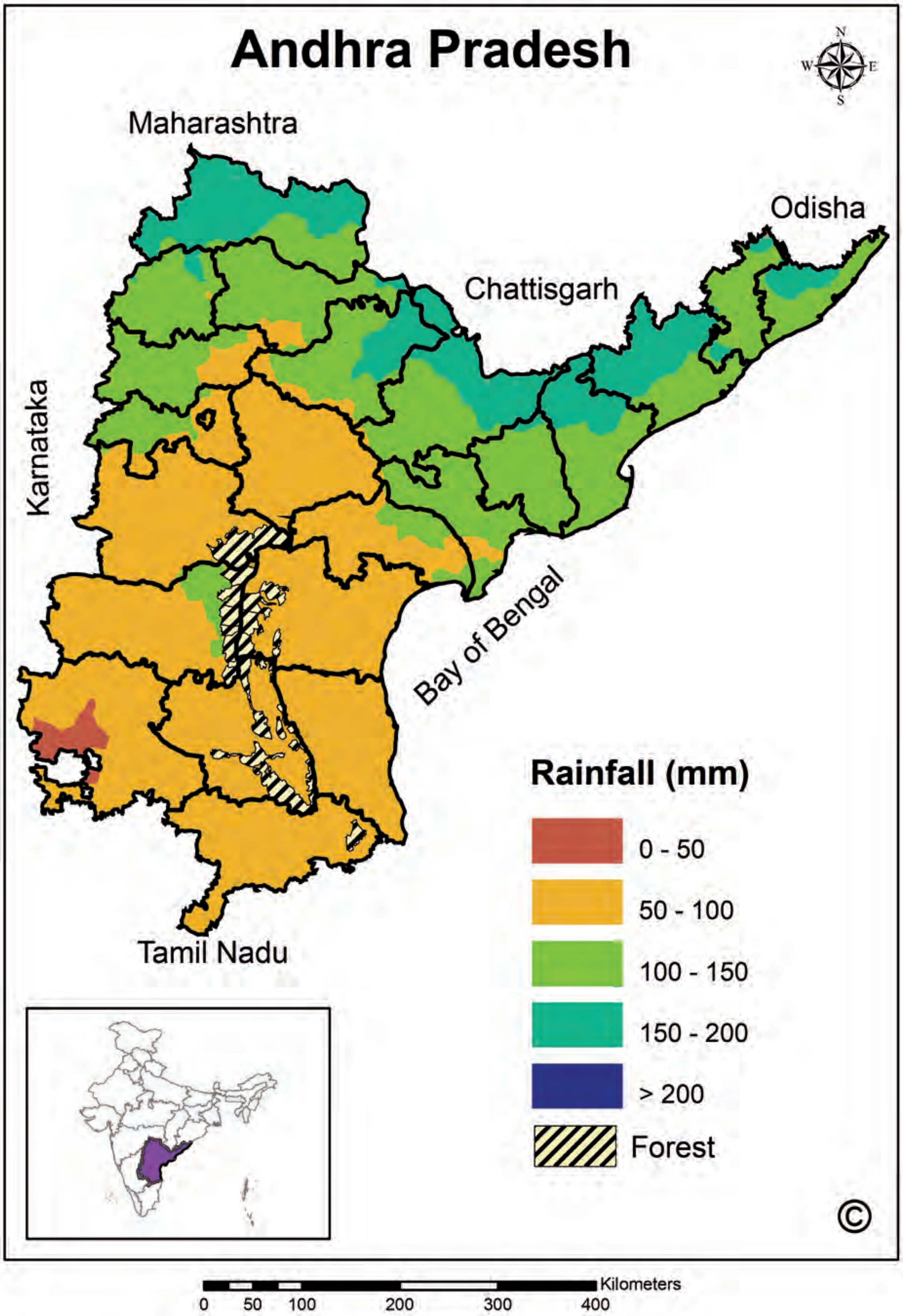

Fig. 66 f: Rain in June in Andhra Pradesh

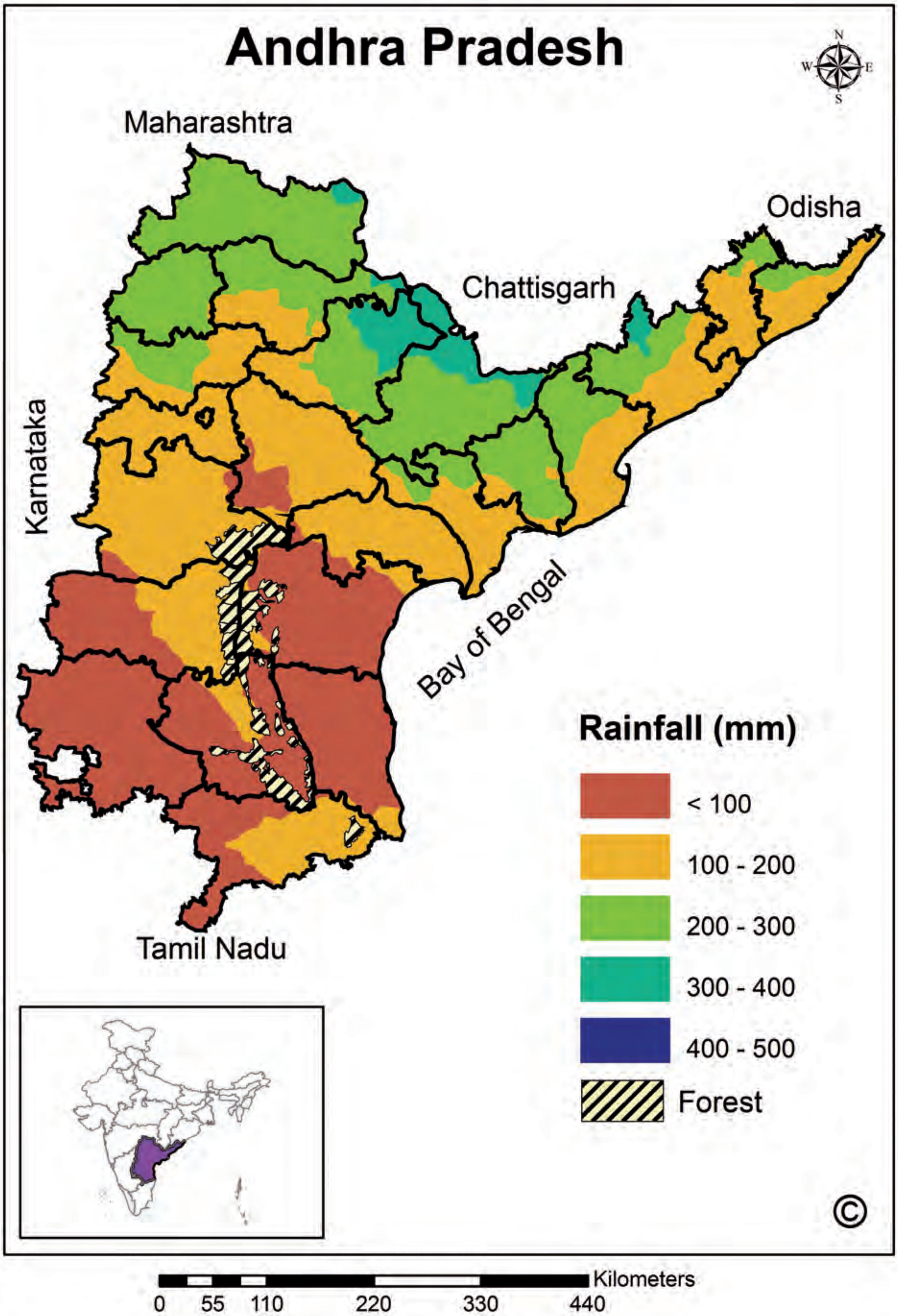

Fig. 66 g: Rain in July in Andhra Pradesh

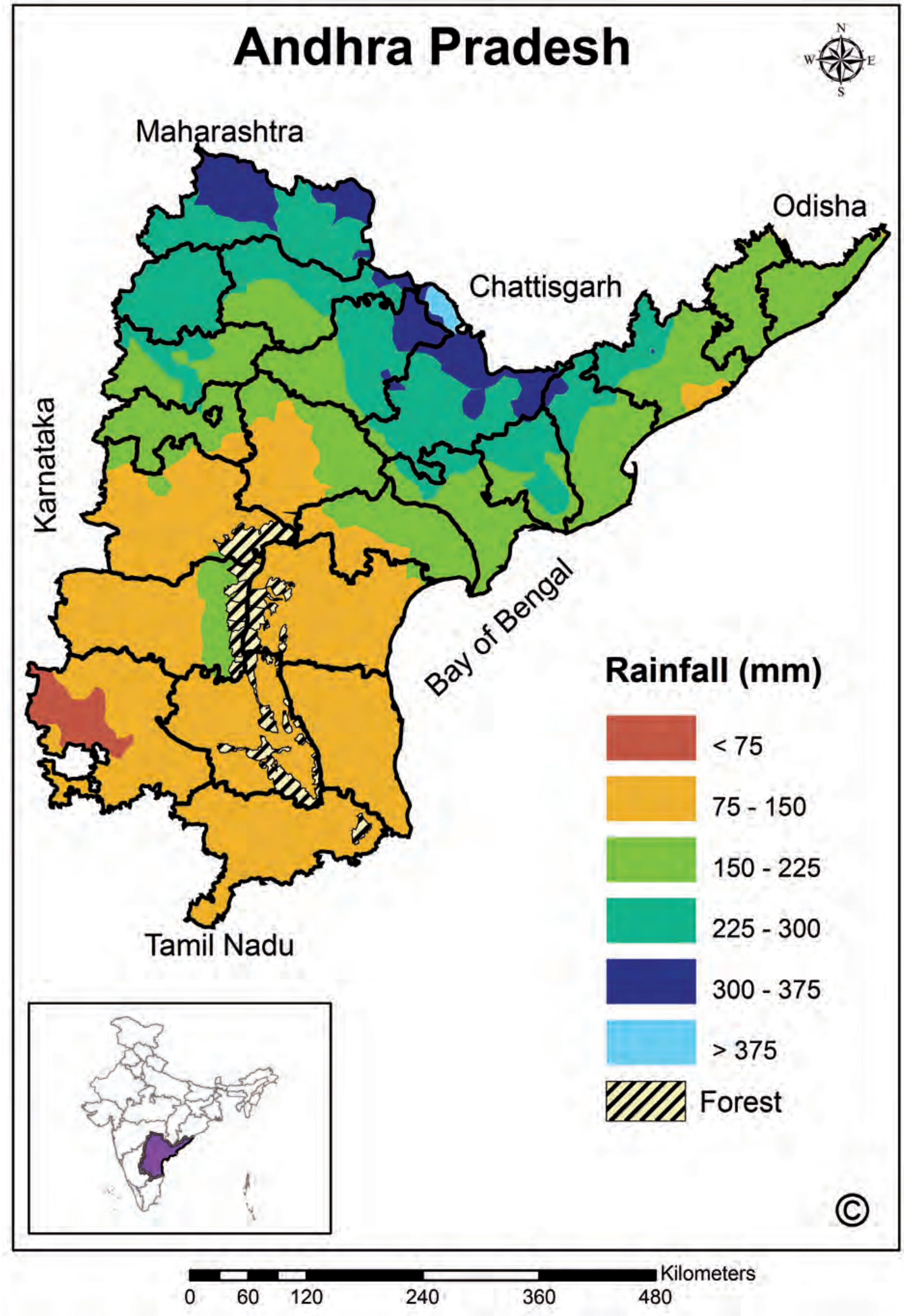

Fig. 66 h: Rain in August in Andhra Pradesh

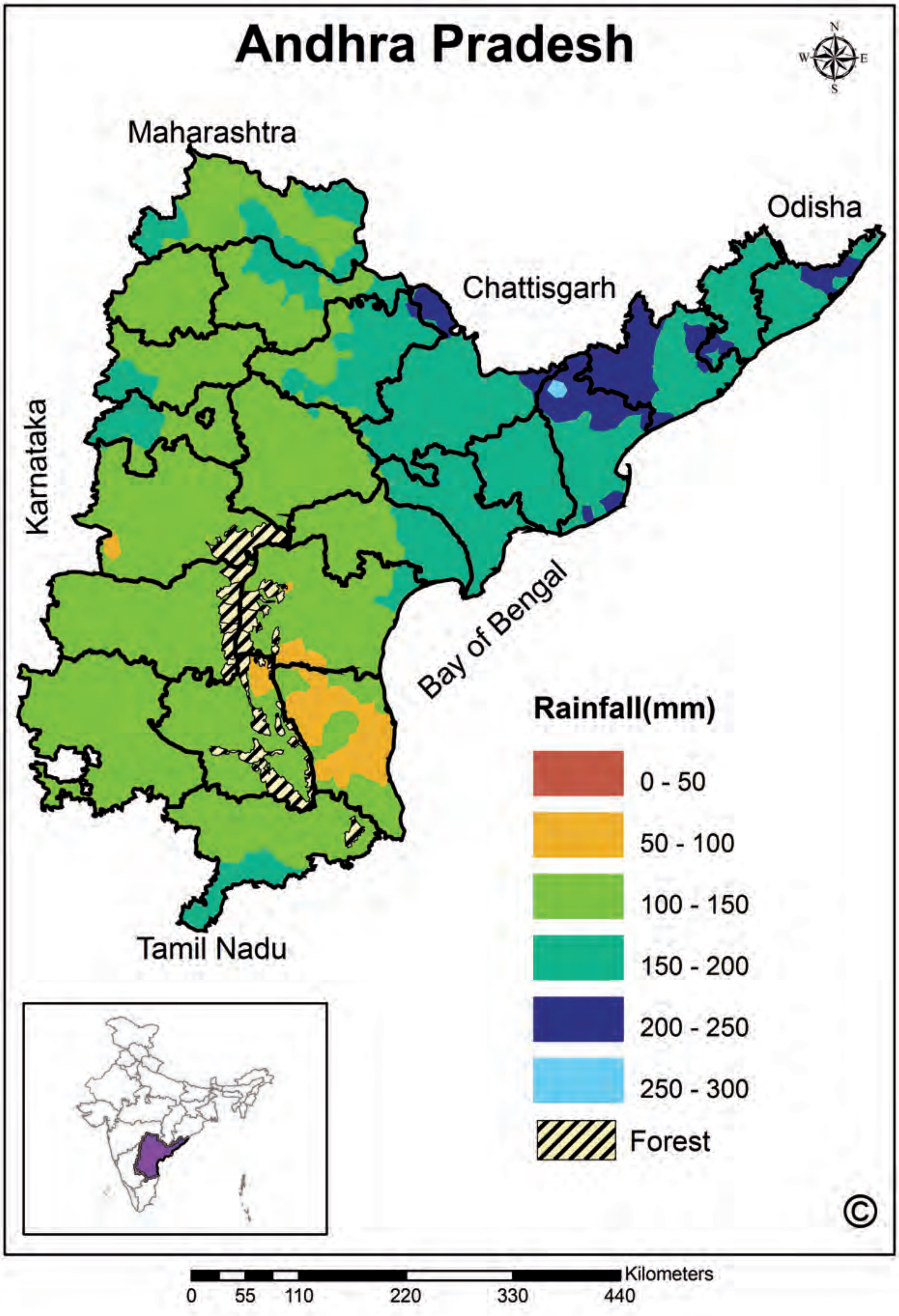

Fig. 66 i: Rain in September in Andhra Pradesh

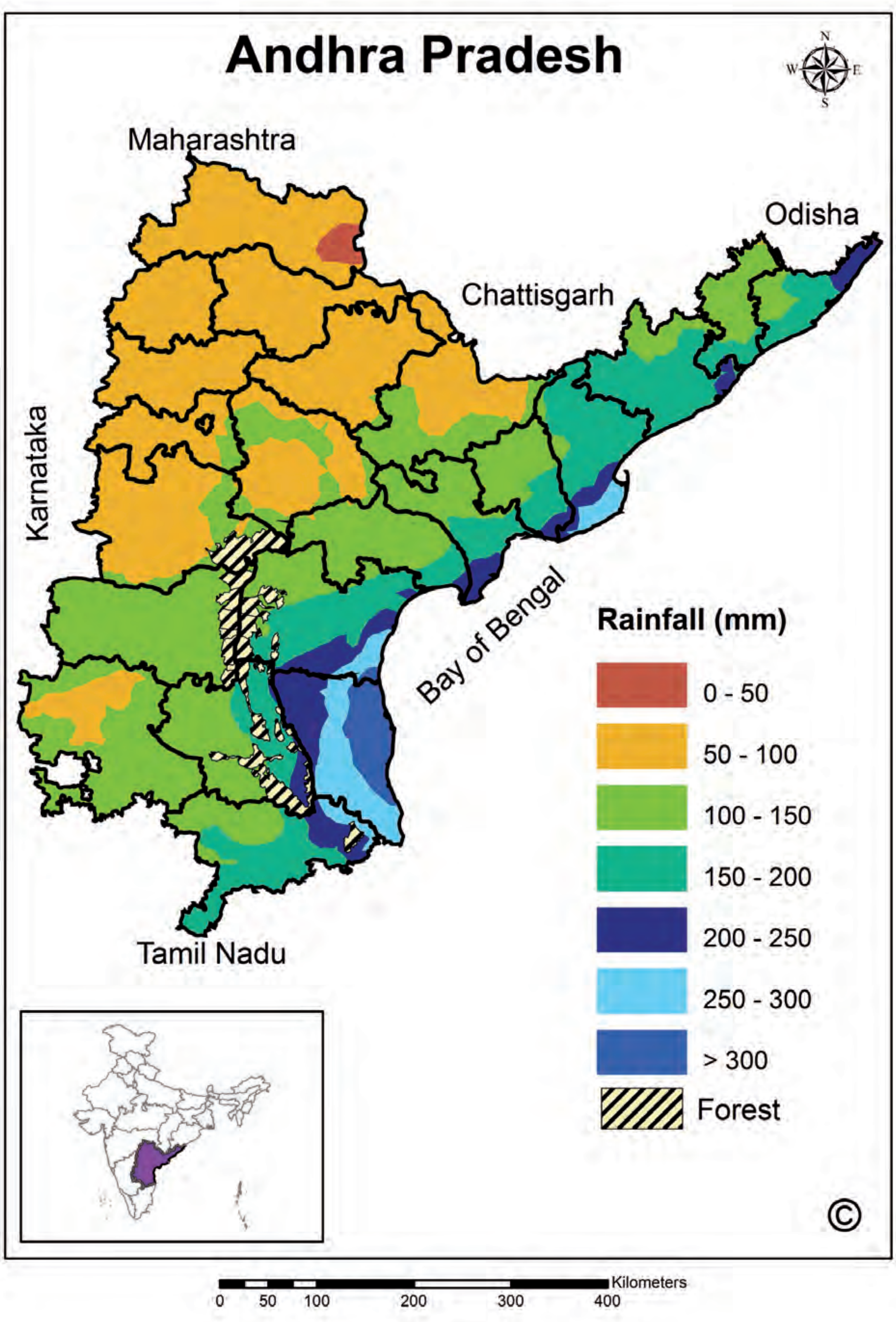

Fig. 66 j: Rain in October in Andhra Pradesh

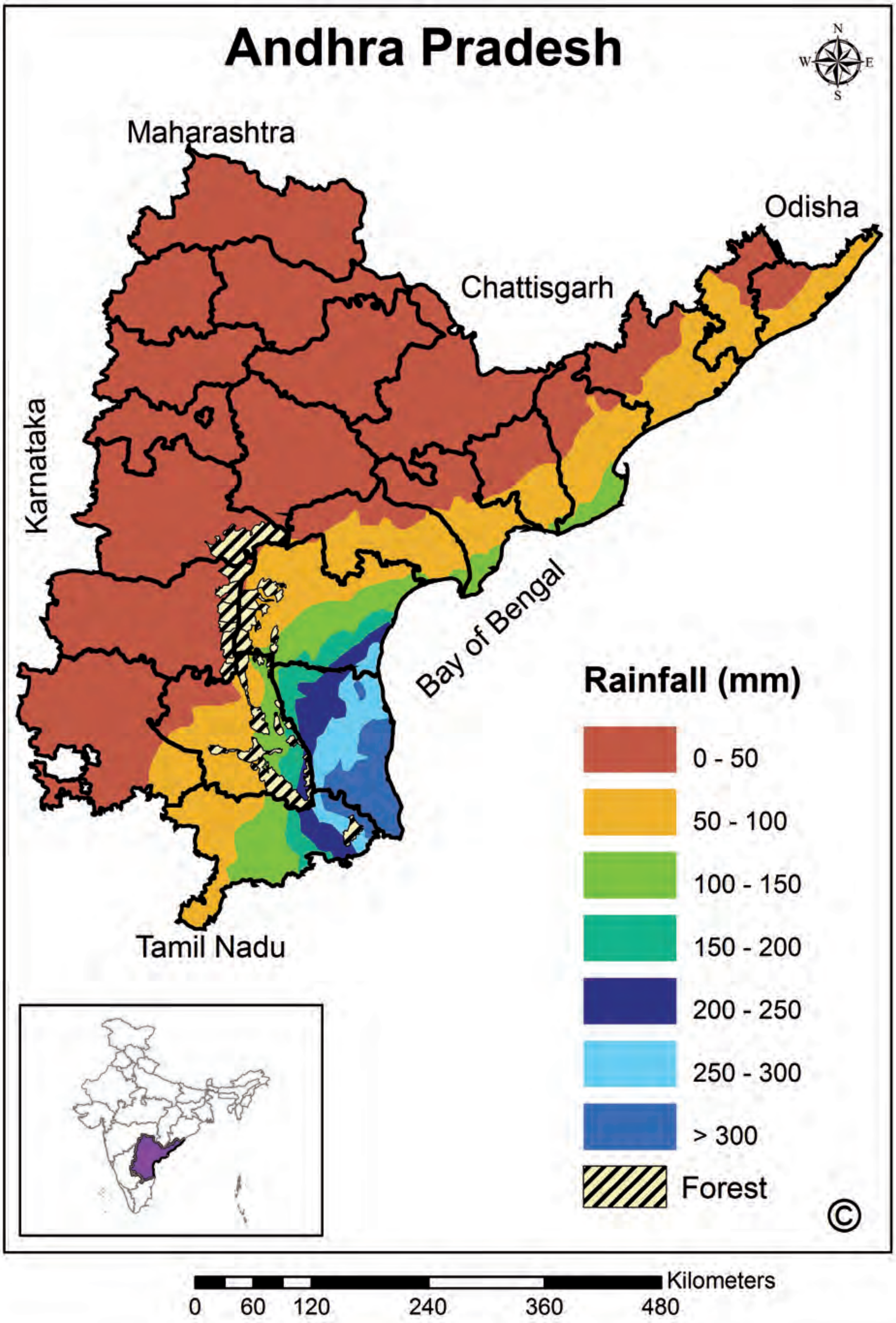

Fig. 66 k: Rain in November in Andhra Pradesh

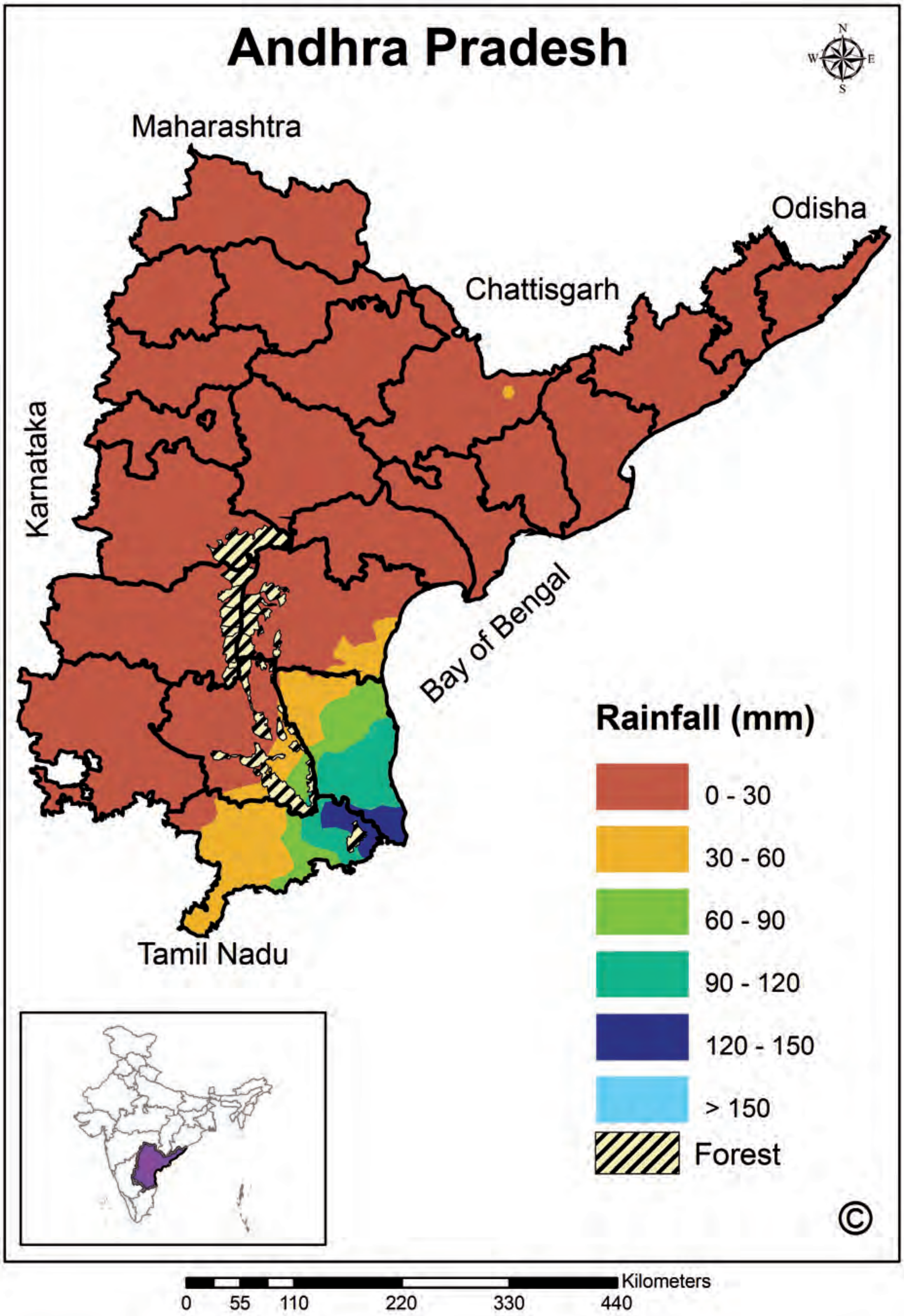

Fig. 66 l: Rain in December in Andhra Pradesh

It is not the total amount of rainfall on a monthly basis that is vital, but the number of rainy days in a month determine the distribution of rain, this is what matters the most. District-wise average number of rainy days on a monthly basis are furnished in the Table 11. It may be observed that highest frequency is noticed during August (10 days) followed by July (9 days) and September (8 days) (Fig. 67). Amongst the 22 districts in the state, 15 districts showed highest number of rainy days during August. In the *Rayalaseema* region (for except Kurnool), all other districts recorded maximum number of rainy days during October. As in the case with rainfall amount, SPSR Nellore district recorded the highest number of rainy days during the months of October and November.

Table 11: Mean monthly distribution of rainy days in different districts of Andhra Pradesh

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adilabad	1	0	1	1	1	8	13	13	8	4	1	0
Anantapur	0	0	0	1	3	3	4	5	6	6	3	0
Chittoor	0	0	1	1	3	4	6	6	7	8	7	3
YSR Kadapa	0	0	0	1	2	4	5	6	6	7	5	1
East Godavari	0	1	1	1	3	7	11	11	9	9	3	1
Guntur	0	0	0	1	2	5	8	9	7	7	4	1
Karimnagar	1	0	1	1	1	7	12	11	7	4	1	0
Khammam	0	0	1	1	2	8	13	13	8	5	1	0
Krishna	0	0	1	1	2	6	10	10	8	7	3	1
Kurnool	0	0	0	1	3	5	7	8	7	6	2	0
Mahabubnagar	0	0	0	1	2	5	8	9	7	5	1	0
Medak	0	0	1	1	1	7	10	11	7	4	1	0
Nalgonda	0	0	0	1	1	5	8	8	7	5	2	0
SPSR Nellore	1	0	0	1	2	3	5	6	6	9	9	4
Nizamabad	0	0	1	1	1	8	12	13	7	4	1	0
Prakasam	0	0	1	1	2	4	6	7	7	8	5	1
Ranga Reddy	0	0	1	1	2	7	10	10	8	5	1	0
Srikakulam	0	1	1	2	3	7	10	11	10	7	2	0
Visakhapatnam	0	1	1	2	4	7	10	11	10	8	3	0
Vizianagaram	1	1	1	2	4	8	10	10	10	7	3	1
Warangal	0	0	1	1	2	7	12	11	7	5	1	0
West Godavari	0	0	1	1	2	7	11	12	9	8	3	0
State	**0**	**0**	**1**	**1**	**2**	**6**	**9**	**10**	**8**	**6**	**3**	**1**
Stan. dev	**0**	**0**	**0**	**1**	**1**	**2**	**3**	**2**	**1**	**2**	**2**	**1**
CV	**49**	**59**	**41**	**49**	**40**	**26**	**29**	**25**	**16**	**27**	**71**	**120**

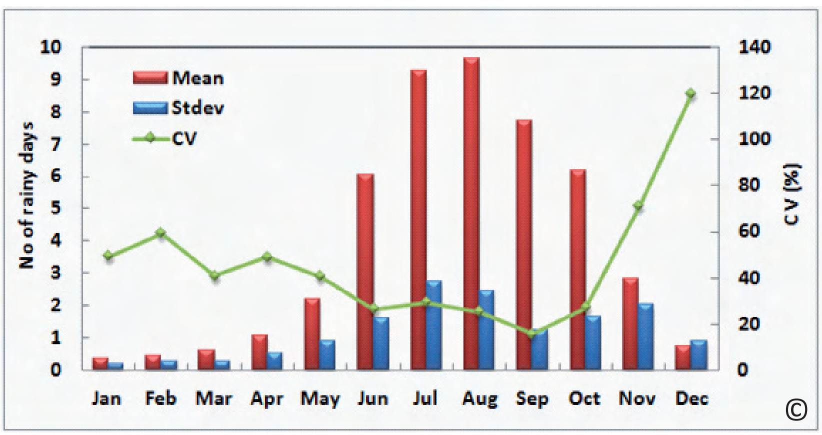

Fig. 67: Average monthly number of rainy days for Andhra Pradesh

4.7. Distribution of weekly rainfall

Commencement of growing season, length of growing season, choice of cropping systems, allocation of resources and inputs depend significantly on the weekly distribution of rain. Distribution of rain on a weekly basis for the state and for the individual districts along with their statistics are presented in Table 12. Considerable rain (> 20 mm / week) over the state occurs in the period from 23 Standard Meteorological Week (SMW) (4-10 June) to 44 SMW (29 Oct - 4 Nov). This indicates a total growing period of 22 weeks (around 150 days). Eight weeks exhibit less than 30 per cent variability and in remaining weeks it is more than 40 per cent even reaching to 67 per cent during 43-44 SMW.

In majority of the districts, except Anantapur and SPSR Nellore, the rainy season commences in the 24th SMW and ends by 40th SMW. In Chittoor, SPSR Nellore and Prakasam districts, the rainy season is limited to 38 to 49 SMW. SPSR Nellore district has recorded the highest weekly rainfall of 110 mm in 44 SMW, however, this rainfall situation is associated with high coefficient of variation (>100%) due to large inter-annual variability and thus has a low dependability. Isolated rainfall events are noted over the entire state during 50 to 20 SMW and the rains get momentum with the onset of monsoon from 21 SMW onwards.

4.8. Distribution of dependable annual rainfall (@ 75 per cent probability)

Average values of rain are simple indicators of rainfall over a period or a region. The associated risk with quantum information of rain are not considered. The amount of rain that can be depended upon enables development of several farm decisions / strategies. By analyzing probability analysis, of receiving a certain amount of rainfall, the variability in the rainfall can be accounted for and strategies can be evolved accordingly. Dependable rainfall for agricultural purposes is generally taken as the expected amount of rainfall with 75% probability. Hargreaves (1974[4]) defined the dependable precipitation as the rainfall amount received at 70% probability. In rainfed agriculture, dependable / assured rainfall helps in proper crop planning. For moisture sensitive crops or high-value crops, a higher level of probability may be more appropriate (Sivakumar and Gnoumou, 1987[5]). Keeping its importance in view, expected rainfall at 75 per cent probability were worked out using an incomplete gamma distribution method on annual and seasonal basis for all *mandals* of Andhra Pradesh.

4.9. Annual rainfall at 75 per cent probability

Highest annual rainfall to the tune of more than 1000 mm is noticed in 20 *mandals* that are mostly located in the Visakhapatnam district (7 *mandals*), followed by the Khammam district (3 *mandals*), two each in East Godavari, SPSR Nellore, Srikakulam, Vizianagaram districts and one each in Chittoor and Warangal districts. Hence, it is evident that in these *mandals* there is high potential for cultivation of high value / long duration / high water demand crops / double cropping systems. Expected annual rainfall ranges between 800 and 1000 mm in the *mandals* closer to the sea in Coastal Andhra region, Chittoor district in the *Rayalaseema* region and northern part of *Telangana* region (Fig. 68). Numerically, 199 *mandals* receive 800-1000 mm rainfall annually. Cultivation of high value / long or medium duration crops in these *mandals* is very much possible with less risk.

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[4] Hargreaves, George, H. 1974. Estimation of Potential and Crop Evapotranspiration. Transactions Americal Society of Agricultural Engineers. 17 (4): 701 - 704.

[5] Sivakumar, M.V.K., and Faustin Gnoumou. 1987. Agroclimatology of West Africa: Burkina Faso. Information Bulletin no.23. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics

Table 12: Mean weekly rainfall in different districts of Andhra Pradesh

Week No.	Adilabad	Anantapur	Chittoor	YSR Kadapa	East Godavari	Guntur	Karimnagar	Khammam	Krishna	Kurnool	Mahabubnagar	Medak	Nalgonda	SPSR Nellore	Nizamabad	Prakasam	Ranga Reddy	Srikakulam	Visakhapatnam	Vizianagaram	Warangal	West Godavari	State	SD	CV (%)
1	1.2	0.1	1.8	0.6	3	2.5	1.5	1.2	1.9	0.3	0.4	0.7	0.8	4	1	3	0.5	1.5	2.6	3.6	1.6	2.2	1.6	1.1	67
2	3.3	0.4	1.5	0.3	2.1	0.7	3.3	2.5	1.7	1	0.8	2.2	1.8	6.5	2.5	2.3	1.1	1.6	1.6	7.5	2.1	1.5	2.2	1.7	80
3	1.9	0.3	1	0.2	0.6	0.3	2	0.9	0.6	0.2	0.3	1.3	0.9	1.6	2.7	1	1.2	0.3	0.6	0.6	0.7	1	0.9	0.6	71
4	1.1	0.1	0.2	0	0.3	0.2	2.5	0.5	0.3	0.1	0.1	1.5	0.7	0.4	1.7	0.4	1	1.5	1	1.6	2.1	0.1	0.8	0.7	93
5	2.8	0.2	0.6	0.1	0.4	0.3	1.8	1.3	0.2	0.2	0.2	0.8	0.5	0.5	1.5	0.1	0.9	0.8	0.8	2.1	0.6	0.3	0.8	0.7	93
6	1.8	0.4	0.6	0.5	3.5	2.8	2.1	1.4	2.3	0.7	1.6	0.7	1.7	1.8	1.2	2.5	0.7	3	3.5	9.6	2.2	1.6	2.1	1.9	92
7	2.1	0.7	4.7	1.3	2.9	2.2	1.8	2.4	2.5	0.8	0.4	1.2	1.1	7.3	1.5	2.1	1.5	5	3.1	4.8	2.7	1.8	2.4	1.7	68
8	1.5	0.2	1.8	0.5	2.8	2.5	1.6	1.8	2.4	0.4	1	0.6	1.2	2.2	1.2	2.5	0.8	4.9	3.7	3.8	0.9	2.3	1.8	1.2	66
9	1	0.6	0.6	0.5	1.8	1.5	1.9	1.5	1	0.7	0.6	1.1	1	0.5	1.2	1.8	0.6	2.7	1.3	2.4	0.7	2.8	1.3	0.7	57
10	2.5	2.2	3	2	3.6	2.9	3.9	2.6	3.2	2.2	2.9	2.7	2.6	1.6	3.6	3.4	2.6	3	2.8	12.3	3.8	3	3.3	2.1	64
11	1.5	1.3	2.2	1	2.5	1.5	1.7	2.2	1.9	0.9	1.2	1.4	1.4	2.3	1.9	2.1	1.7	5.1	5.1	4.5	2.3	2.1	2.2	1.2	55
12	1.4	1.4	2.4	1.6	2.7	2.4	2.6	4.1	3.3	2.3	3.2	3.7	3.6	1.7	1.8	3.2	4.5	3	3	3.8	4.7	3.2	2.9	1	33
13	1.6	1.9	2.6	1.1	2.7	1.2	1.9	1.5	1.5	1.7	1.5	2.9	1.3	0.7	2.5	1.5	3.3	4.6	5.8	4.8	1.7	1.8	2.3	1.3	58
14	2.9	2	3.6	1.7	3.1	1.6	4	3	1.1	2.2	2.5	3.9	2.2	2.4	3	1.9	3.9	5	7.4	11.8	2.5	1.4	3.3	2.3	70
15	1	3.1	3.9	2.7	3.8	2.3	2.4	2.7	1.4	2.8	2.6	2.3	1.4	3.1	1.3	2.7	2.8	5.4	7.7	8.6	2.2	2.3	3.1	1.9	61
16	4.1	3.6	5.3	2.4	8.5	6.5	4.2	8.1	5.8	4.2	4.2	5.4	4.3	3.9	3.9	4.7	6.1	7.4	12.7	11.3	5.7	7	5.9	2.5	43
17	1.7	4.4	5.9	4.1	4.6	3	2.6	3.6	3.9	5.9	4	3.1	2.5	2.8	1.2	2.1	4.6	8	10.7	8.7	2.5	4.3	4.3	2.4	55

Week No.	Adilabad	Anantapur	Chittoor	YSR Kadapa	East Godavari	Guntur	Karimnagar	Khammam	Krishna	Kurnool	Mahabubnagar	Medak	Nalgonda	SPSR Nellore	Nizamabad	Prakasam	Ranga Reddy	Srikakulam	Visakhapatnam	Vizianagaram	Warangal	West Godavari	State	SD	CV (%)
18	3.5	6	10.8	6.9	7.2	4.2	3.3	6.2	5.9	5.2	2.9	3.6	4.3	9.1	2.3	5.1	5.5	10	12.6	11	4	7	6.2	2.9	47
19	3.6	8.2	14.7	10.2	30.3	12.4	6.1	12.4	15.3	8.1	7.3	6.7	5.9	19.4	5.1	15	6.5	24.7	32.9	31.5	5.7	18.7	13.7	9.1	66
20	4.2	11.9	12.8	8.5	11.6	7.6	5.6	9.8	8.6	10.7	8.7	5.8	5.4	5.5	5.8	8.3	9.4	15	17.6	16.1	8.7	12.7	9.6	3.7	39
21	2.8	14.2	14.5	11.1	9.1	10.4	2.9	11.2	8.7	11.4	7.1	4.4	5.3	6.4	3.6	10.4	6.8	15.6	17	18.2	4.7	7.6	9.2	4.6	50
22	6.6	13.8	14.1	8.3	11.9	11	6.7	12.5	10.5	11.8	7.5	7.4	8.3	4.9	6.6	6.9	8.5	10.7	15.6	15.2	8.2	10	9.9	3.1	31
23	19.6	17.1	18.3	14.2	22.1	18.5	19.6	22.1	17.3	16.8	17.4	21.4	17.8	11.4	21.5	13.5	20.7	24.5	27.7	28.6	20.9	19.7	19.6	4.1	21
24	45.8	16.5	21.2	22.6	41.9	28.9	41.4	46.2	39.2	23.9	21.3	32.2	32	15.4	42	20.5	31.8	43.9	42.9	37	41.6	39.4	33.1	10.2	31
25	50.6	8.3	13.5	13.7	28.6	18.1	32	35	22.3	21.5	20.2	32.6	18.9	11	40.8	14.4	27.7	38.5	32.9	31.6	30.2	25.1	25.8	10.7	42
26	58.1	6.7	11.8	9.4	37.9	21.1	46.5	40.2	30.9	16	21.7	31.9	20.6	9.9	45.6	12	26.3	36.3	32.5	35.5	42.3	37.4	28.7	14.1	49
27	59.5	9.4	18.4	16	40.1	29.8	51.8	53.3	39.7	20	27.2	37.8	29.2	18.3	48.6	19.9	34.4	38.5	37.9	33.4	48.7	42.1	34.3	13.5	40
28	65.4	16.3	22.5	20.1	42.6	27	55.1	61.8	37	23.2	25.4	41.3	28.2	16.1	55.1	13.7	33.5	35	35.8	36.5	60.3	41.4	36	15.6	43
29	64.1	15.6	23.7	21.3	44.1	32.7	49.8	62.3	40.5	23	26.5	38.3	30	20.1	50.8	24	34	45.8	39.9	42.6	54.5	47.4	37.8	13.8	37
30	69.4	15.5	22.6	23.4	45.1	40.6	61.1	73.6	50.9	29.5	36.9	53.9	38.5	19.7	68.1	23.2	45.2	40.8	42.8	40.6	62.5	54.9	43.6	17	39
31	76.1	13.3	23.7	23.1	45.2	39.9	62	74	46.4	27.7	32	52	35.9	18.6	73.1	22.4	42	52.7	43.5	35.7	69.9	51	43.6	18.8	43
32	78.2	15.1	22.7	22	56.6	31.9	64.2	72.5	48.9	29.3	30.2	45.6	33.1	18.6	71.7	19.1	39.9	43.9	42.8	37	58.6	61.9	42.9	19.1	44
33	56.1	14	27.8	22.8	44	38.7	46.4	60.2	45.3	23.7	32.7	45.7	36.9	21.4	54.1	22	42.9	42.8	41.1	45.4	49.6	49	39.2	12.6	32
34	67.4	25.9	28.3	29.9	40.1	40.7	51.7	53.1	43.9	31.1	33.7	46.1	32.4	24.6	60.7	30.8	43	40.3	38.5	41	45.5	48.4	40.8	11.1	27
35	57.8	20.6	22.5	22.8	39.6	27.7	43.3	48.8	37	29.9	29.1	37.9	28.6	19.8	50.7	23.4	31.3	46.6	41.8	35.1	45.4	41.6	35.5	10.8	30

Week No.	Adilabad	Anantapur	Chittoor	YSR Kadapa	East Godavari	Guntur	Karimnagar	Khammam	Krishna	Kurnool	Mahabubnagar	Medak	Nalgonda	SPSR Nellore	Nizamabad	Prakasam	Ranga Reddy	Srikakulam	Visakhapatnam	Vizianagaram	Warangal	West Godavari	State	SD	CV (%)
36	44.2	22.3	29.3	25.9	39.7	29.2	38	40.6	32.8	24	24.8	33	26.9	17.4	42.9	20.7	30.5	42.4	42.1	38	36.8	36.5	32.7	8	25
37	27.8	30.7	32.1	27.8	36.5	29.6	28.5	39.9	32	28.9	26.7	30.5	29.2	18.8	31.6	22.1	31	47.9	44.1	48	33.4	34.3	32.3	7.3	23
38	33	36.9	34.5	34.5	53.7	46.5	38.1	46.5	50.2	36.1	36.4	34.5	42.4	31.7	29.3	38.5	42.7	57.9	50.9	52	41.2	49.3	41.7	8.1	19
39	25.9	30.8	37.4	28.6	47.5	40.8	25.9	29.2	37.1	35.4	34.2	34.2	34.1	32.5	31.8	38.3	36	42.1	42.1	40.4	26.4	41	35.1	5.9	17
40	28.8	35.9	39.2	37.6	57.1	44	30.6	44.2	46.5	45	38.3	32.7	40	38.8	30.4	43.2	38	68	69.2	49.5	35.6	52.9	43	10.9	25
41	14.9	24.5	30.6	21.5	45.7	24.6	14	24.3	32	25.4	21	15.6	21.7	33.1	13.7	36.1	20.2	36	39.7	31.1	18.5	37.5	26.4	9.1	34
42	18.8	19.4	33	34	46.9	28.2	18.1	20.1	34.2	21.6	17.7	17.4	17.5	63.7	22	37	18.2	49.9	46.3	38.5	19.5	35.2	29.9	13.1	44
43	13	20.8	42	31.4	30.6	25.9	15.8	12.4	24	17.4	10.8	15.7	15.4	85.7	15.4	47.8	15.1	17.9	23.9	18.6	16	23.4	24.5	16.6	68
44	5.1	18.7	48.5	34.2	43.7	35.9	9.4	12.3	39.6	13.6	11.8	10.6	21.1	109.9	7.5	56.7	14	31.9	32.2	24.7	12.7	29.9	28.4	23.2	82
45	1.5	11.4	35.8	21.1	20.3	15.6	3.6	6.3	14.4	6.3	3.5	3.8	7.8	75.5	1.8	27.9	2.8	17.3	14.2	20.9	5.1	15.8	15.1	16.3	108
46	3.9	8.8	42.9	24.5	19.4	18.8	5	3.5	15.4	7.2	5.9	5.3	7	83.1	4.3	35.5	7.2	10	15.9	9.9	4.8	14.8	16	18.2	114
47	2.5	4.5	24.4	12.6	14.2	12.6	2.2	5.6	10.7	2.4	2.3	2.5	3.5	43.1	3.2	20.4	2.1	4.9	10.9	11.4	2.7	8	9.4	9.8	104
48	1.5	3.7	23.9	11.4	9.1	7.8	1.1	2.8	7	3.7	1.9	1.3	2.7	40.7	1.8	13.1	1.1	4.6	4.7	6.1	1.8	7.7	7.3	9.2	126
49	0.4	2.9	22.4	11.9	8.3	5.9	1.7	2.5	5.1	2.1	2	1.2	1.4	36.6	1	10.2	0.9	3.3	4.3	9.8	2	4.9	6.4	8.5	132
50	0.3	1.3	14.7	4.3	3.9	6.3	0.4	1.8	6.8	1.3	0.5	0.4	0.5	21.2	0.4	8.1	0.7	1.6	2.7	3.1	0.3	5.1	3.9	5.2	134
51	0.5	0.7	9	1.9	0.5	0.5	0.4	0.4	0.3	0.1	0	0.1	0	12.2	0.3	2	0	1.3	1.4	1.7	1	0.4	1.6	3	192
52	1.6	1.5	9.9	2.7	1.5	1.3	1.7	0.5	1	1	0.4	0.9	0.7	11.9	1.3	2.1	0.6	0.6	1	0.8	1.5	1	2.1	2.9	142

Table 13: Amount of dependable annual rain (@75% probability) occurred in different districts of Andhra Pradesh

District	Rainfall (mm) at 75% probability
Adilabad	725
Anantapur	405
Chittoor	679
YSR Kadapa	504
East Godavari	813
Guntur	636
Karimnagar	629
Khammam	835
Krishna	728
Kurnool	503
Mahabubnagar	459
Medak	585
Nalgonda	490
SPSR Nellore	817
Nizamabad	703
Prakasam	584
Ranga Reddy	589
Srikakulam	832
Visakhapatnam	828
Vizianagaram	814
Warangal	703
West Godavari	785

445 *mandals* in the state which are majorly spread in coastal Andhra region, Chittoor district of *Rayalaseema* region and all districts of the *Telangana* region (except Nalgonda and Mahabubnagar) receive annual rainfall in the range of 600-800 mm. An expected annual rainfall in the range from 400 - 600 mm is observed majorly in interior parts of the state comprising districts of Mahabubnagar, Nalgonda, Kurnool, YSR Kadapa, Prakasam, Anantapur, Guntur and some *mandals* of Chittoor, Ranga Reddy, Medak, Karimnagar and Warangal districts. Lowest annual rainfall expected (at 75 per cent probability) in Anantapur district and also in some pockets of YSR Kadapa, Mahabubnagar, Nalgonda districts. Rainfed farming and pastoralism are the mainstay in these areas and practicing of crop-based agriculture is a highly risky proposition. Crop failures are common here due to a large inter-annual as well as intra-seasonal variation of rain.

It is seen from the above that around 1/3rd of the geographical area of the state of Andhra Pradesh receives annual rainfall between 400 and 800 mm at 75 per cent probability. These areas can be classified as semi-arid / dry sub-humid climates where rain pattern is inherently erratic. For a successful production of a crop, meticulous preparation is needed for evolving an efficient cropping pattern / land use based on an integrated farming system.

4.10.1. Trends in annual, seasonal rainfall and rainy days

Daily precipitation has been segregated into seasonal (Southwest monsoon) and annual rainfall. The significance of the trends was tested by Mann-Kendall test (Fig. 69). Around 85 percent of the *mandals* in the state showed no significant trend. However, majority of the *mandals* in Medak district showed declining trend in annual rainfall followed by Karimnagar, Mahabubnagar and Nalgonda districts. On the other hand, increasing trend in annual rainfall is observed in many *mandals* of Anantapur, Kurnool, Prakasam and also a few *mandals* of SPSR Nellore, Krishna and Vizianagaram districts. Considering the geographical area showing a tendency in change in rainfall amounts, in six districts but more than 90% of the area did not show any significant change (Table. 14). About 11% of the total geographical area in Prakasam district and 10% in Vizianagaram district showed strong increased rainfall trends, whereas, 17% of the geographical area in Medak and 9% in Vizianagaram showed a statistically significant decreasing trend. In number of annual rainy days, no significant increasing / decreasing trend is seen in 80 per cent of *mandals*. Most of the *mandals* of drought-prone districts of *Rayalaseema* region (Anantapur, Chittoor, YSR Kadapa and Kurnool) showed an increasing trend (Fig. 70). This indicates that the distribution of rainfall during summer monsoon may improve in these districts which would help increasing crop yields. At the same time, mostly declining trend is noticed in several *mandals* of *Telangana* region, Prakasam, Guntur and West Godavari districts.

For the SWM rainy season, in 17 out of 45 *mandals* a declining trend was observed in Medak district (Fig. 71). On geographical scale there are about 10 districts where more than 90% of their area showed no significant trend (Table. 15). Increasing trend over 15% of the geographical area is noted in Visakhapatnam district, 9% each in Khammam and Kurnool districts and 8% in Chittoor. In Medak 10% of the geographical area showed a strong decreasing tendency. At the same time, increasing tendency in summer monsoon rainfall is observed in larger number of *mandals* of Khammam and Visakhapatnam followed by Kurnool and Krishna districts. The trend of number of rainy days during the summer monsoon season showed same pattern as in the case of amount of rainfall (Fig. 72). However, a declining trend is seen in about 20 *mandals* of Nalgonda district.

4.10.2. Trends in receipt of heavy rainfall events in various districts of Andhra Pradesh

Heavy / very heavy rainfall events results in flash floods leading to extensive top soil erosion, landslides in hilly terrain and an extensive crop damage. Goswami *et al.,* (2006)[6] reported that in spite of considerable year to year variability, there were significant increases in the frequency and intensity of extreme monsoon rain events over the past 50 years in central India. Further, IPCC (2007)[7] in its fourth assessment report stated that the climate change in the recent decades is mainly attributable to anthropogenic activities and extreme rainfall events would occur frequently especially in tropical countries. Considering the extensive crop damage due to heavy rainfall events, policy makers are interested to identify areas vulnerable to heavy rainfall events. Hence, trends in heavy rainfall events on seasonal (Southwest monsoon) and annual rainfall basis under two categories *viz.,* 75-100 mm and more than 100 mm rain recorded in 24 hour period using *mandal* level daily rainfall data for the state of Andhra Pradesh has been assembled. Mann-Kendall test has been applied to understand the significance of heavy rain events.

4.10.3. On annual basis

In general, no significant trend has been observed in major parts of the state under both categories (75-100 mm and more than 100 mm). In the 75-100 mm category, about 1005 *mandals* and in the more than 100 mm category, 1049 *mandals* did not show any significant difference. However, significant increasing trend is noted in many *mandals* of Krishna, West Godavari, Guntur, SPSR Nellore and Vizianagaram districts. A declining trend is observed in Karimnagar and Medak districts under

[6] B.N. Goswami, V. Venugopal, D. Sengupta, M.S. Madhusoodanan, Prince K. Xavier. (2006). Increasing trend of extreme rain events over India in a warming environment. Science, 314:1442-1445.

[7] IPCC, Climate Change. (2007). Climate change impacts, adaptation and vulnerablility. Summay for policymakers. Inter-Governmental panel on climate change.

75-100 mm category (Fig. 73). In the *Rayalaseema* region, a decreasing trend is observed in *mandals* like Chintha Kommadinne, S. Mydukur, Yerraguntla, Kadiri, Tadimmarri and Uravakonda only while Rayachoti *mandal* in YSR Kadapa district showed an increasing tendency. For more than 100 mm per day rainfall category, only 32 *mandals* in the state showed an increasing trend with a maximum number of *mandals* in Krishna (7 *mandals*) followed by Visakhapatnam (5 *mandals*), Adilabad, Khammam, Prakasam (each 4 *mandals*), Warangal, Guntur (each 2 *mandals*) and each one *mandal* in Mahabubnagar, SPSR Nellore and Vizianagaram districts (Fig. 74). At the same time, declining trend has been observed in 20 *mandals* with a maximum number of *mandals* observed in SPSR Nellore (4 *mandals*) followed by West Godavari (3 *mandals*) district.

4.10.4. Heavy rainfall events during Southwest monsoon season in Andhra Pradesh

Almost same pattern as that of annual rainfall is noted in the heavy rainfall trends during the SWM period across Andhra Pradesh. The state as a whole, showed significant increasing and declining trends in 33 and 27 *mandals*, respectively under 75-100 mm category. Maximum number of *mandals* showing significant increasing trend is seen in Guntur (6 *mandals*) followed by Krishna and Warangal (5 *mandals*). Declining trend is observed in *Telangana* region particularly in Karimnagar and Adilabad districts (Fig. 75). It is evident from the map that a few *mandals* of Khammam, Warangal and Adilabad districts in the *Telangana* region and West Godavari and Visakhapatnam districts in the coastal region showed significant increasing trend under more than 100 mm category (Fig. 76). On the other hand, declining tendency in frequency of occurrence of days with more than 100 mm / day is evident in the southern part of the state (SPSR Nellore, YSR Kadapa, Anantapur and Chittoor districts) and also in the north coastal district (Vizianagaram).

From the above, it is clear that majority of the *mandals* in the state do not indicate any significant increasing and decreasing trend in heavy rainfall events. However, a significant increasing trend is noted in a few *mandals* of northern and coastal districts of the state. This type of information would give insights to the policy makers and farmers towards soil conservation measures as heavy rainfall aggravates soil erosion and also causes extensive crop damage.

4.11. Potential evapotranspiration (PET)

Potential evapotranspiration is defined as “the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water”. Temporal variations of PET and quantification of its trend can serve as a valuable reference data for the regional studies of hydrological modeling, agricultural water management, irrigation planning and water resource management.

The PET values in the present analysis are estimated using “PET Calculator v3.0” (Bapuji Rao, B. *et. al*., 2012)[8]. The input data (mean temperature, relative humidity, sunshine and wind speed) on monthly basis are sourced from *http://www.cru.uea.ac.uk*. The data has a resolution of 10’ (0.16° x 0.16° grid) and is the climatic normal (1961-1990) for each grid. Spatial maps are prepared by estimating PET normals for each grid. The PET thus estimated are averaged for different time periods *viz*., monthly, seasonal and annual. The spatial maps prepared for these periods are presented in Fig. 77 to 81.

4.11.1. Annual

The mean daily PET on an annual basis ranged from 4.9 to 5.9 mm/day in the state. Spatial differences are noticed. Highest PET (5.7 to 5.8 mm/day) is observed in majority area of SPSR Nellore and eastern part of Chittoor district (Fig. 77). Large geographical area of the state experience PET values in the range of 5.3 to 5.7 mm/day. Lowest PET (4.9 to 5.1 mm/day) values are recorded in Visakhapatnam district which is at high altitude.

[8] Bapuji Rao, B., Sandeep, V.M., Rao, V.U.M. and Venkateswarlu, B. 2012. Potential Evapotranspiration estimation for Indian conditions: Improving accuracy through calibration coefficients. Tech. Bull. No 1/2012. All India Co-ordinated Research Project on Agrometeorology, Central Research Institute for Dryland Agriculture, Hyderabad. 60p.

Table 14: Per cent area showing increasing/decreasing trend in annual rainfall in different districts of Andhra Pradesh

District	Total Geographical Area of District (1000 Acres)	Increasing at 99% Significance	Increasing at 95% Significance	Increasing at 90% Significance	Decreasing at 99% Significance	Decreasing at 95% Significance	Decreasing at 90% Significance	No Significant Trend	Area not assessed*
Adilabad	3447	Nil	Nil	2	Nil	Nil	Nil	98	Nil
Anantapur	4024	5	11	2	Nil	Nil	Nil	82	Nil
Chittoor	3117	2	2	4	Nil	1	1	88	2
YSR Kadapa	3172	Nil	4	4	Nil	Nil	Nil	69	22
East Godavari	2281	1	12	Nil	Nil	1	Nil	86	Nil
Guntur	2251	5	2	Nil	Nil	5	5	83	Nil
Karimnagar	2427	Nil	2	1	3	3	3	89	Nil
Khammam	3352	Nil	7	Nil	Nil	Nil	Nil	93	Nil
Krishna	1852	4	5	6	Nil	2	Nil	83	Nil
Kurnool	3685	Nil	6	9	Nil	3	1	70	11
Mahabubnagar	3883	Nil	Nil	Nil	Nil	5	2	83	10
Medak	1989	Nil	Nil	Nil	17	20	8	55	Nil
Nalgonda	3034	Nil	2	Nil	Nil	7	4	88	Nil
SPSR Nellore	2773	Nil	5	7	Nil	Nil	Nil	88	Nil
Nizamabad	1658	Nil	Nil	Nil	Nil	Nil	Nil	100	Nil
Prakasam	3656	11	1	2	2	Nil	5	70	10
Ranga Reddy	1584	2	1	Nil	Nil	4	2	91	Nil
Srikakulam	1258	Nil	Nil	Nil	Nil	5	Nil	95	Nil
Visakhapatnam	2397	3	4	Nil	1	Nil	6	86	Nil
Vizianagaram	1288	10	4	Nil	9	3	Nil	74	Nil
Warangal	2679	Nil	3	3	Nil	6	4	84	Nil
West Godavari	1607	Nil	Nil	Nil	Nil	4	Nil	96	Nil

* Area not assessed due to lack of sufficient length of datum.

Table 15: Per cent area showing any increasing/decreasing trend in Southwest rainfall in different districts of Andhra Pradesh

District	Total Geographical Area of District (1000 Acres)	Increasing at 99% Significance	Increasing at 95% Significance	Increasing at 90% Significance	Decreasing at 99% Significance	Decreasing at 95% Significance	Decreasing at 90% Significance	No Significant Trend	Area not assessed*
Adilabad	3447	Nil	2	Nil	Nil	Nil	Nil	98	Nil
Anantapur	4024	Nil	3	Nil	Nil	Nil	Nil	97	Nil
Chittoor	3117	Nil	8	4	Nil	1	2	83	2
YSR Kadapa	3172	Nil	Nil	2	Nil	Nil	Nil	75	22
East Godavari	2281	1	3	1	Nil	Nil	Nil	95	Nil
Guntur	2251	2	3	5	Nil	1	1	88	Nil
Karimnagar	2427	Nil	3	1	Nil	5	Nil	91	Nil
Khammam	3352	3	9	7	Nil	Nil	Nil	81	Nil
Krishna	1852	3	7	5	Nil	Nil	Nil	85	Nil
Kurnool	3685	Nil	9	6	Nil	1	3	70	11
Mahabubnagar	3883	Nil	Nil	1	Nil	Nil	3	86	10
Medak	1989	Nil	Nil	4	10	6	20	60	Nil
Nalgonda	3034	Nil	Nil	Nil	1	1	3	95	Nil
SPSR Nellore	2773	3	2	2	Nil	2	Nil	91	Nil
Nizamabad	1658	Nil	2	4	Nil	Nil	Nil	95	Nil
Prakasam	3656	Nil	Nil	3	2	4	Nil	82	10
Ranga Reddy	1584	Nil	2	4	Nil	Nil	Nil	94	Nil
Srikakulam	1258	Nil	Nil	Nil	Nil	Nil	Nil	100	Nil
Visakhapatnam	2397	1	15	3	Nil	1	Nil	80	Nil
Vizianagaram	1288	5	5	7	3	7	4	68	Nil
Warangal	2679	3	3	6	Nil	2	2	84	Nil
West Godavari	1607	Nil	Nil	2	Nil	Nil	Nil	98	Nil

* Area not assessed due to lack of sufficient length of datum.

4.11.2. Southwest monsoon season

This is the main rainy season of the state except for few southern districts like SPSR Nellore, Chittoor and parts of Prakasam and YSR Kadapa. PET rates of major geographical area of the state ranged from 5.5 to 5.7 mm/day during this season. Highest rates (5.7 to 6.0 mm/day) are noted in parts of Prakasam, SPSR Nellore and Chittoor districts (Fig. 78). Lowest rates (4.9 to 5.1 mm/day) are noted in parts of Visakhapatnam, East Godavari and Vizianagaram districts which falls under high altitude and tribal zone.

4.11.3. Northeast monsoon season

During this season major area of state experiences PET rates in the range of 4.5 to 4.7 mm/day. Like in the case of annual and SWM season, parts of Visakhapatnam, East Godavari and Vizianagaram districts that fall under high altitude and tribal zone showed lowest PET rates (4.1 to 4.3 mm/day) (Fig. 79).

4.11.4. Summer season

Summer is the hottest season of the year and PET values for major geographical area ranged between 6.6 to 6.8 mm/day. Parts of Prakasam, Kurnool, YSR Kadapa, Srikakulam districts and entire SPSR Nellore district showed highest PET values (6.8 to 6.9 mm/day) (Fig. 80).

4.11.5. Winter season

During winter season highest PET (5.2 to 5.4 mm/day) are noted in parts of SPSR Nellore and Chittoor districts and lowest values (4.4 to 4.6 mm/day) in parts of Adilabad, Visakhapatnam, East Godavari and Vizianagaram districts (Fig. 81).

4.11.6. Monthly PET

The PET rates computed for different months (January to December) are used for spatial maps and these maps are appended in Annexure - III. Amongst the months, PET rates are highest during the month of May and least during the month of December.

4.12. Meteorological drought

Meteorological drought occurs in all the climatic regions of Andhra Pradesh, but its intensity differs from region to region. The frequencies of moderate and severe meteorological droughts were computed based on departures from normal annual rain for all the *mandals* of Andhra Pradesh (as per IMD criteria i.e., 26-50% deficiency is moderate drought, and >50% is termed as severe meteorological drought).

Moderate drought with probability of 8 to 16 per cent occurs in Srikakulam, Vizianagaram, Visakhapatnam, Khammam, Warangal and Medak districts. In fact, majority of the area in the state has 16 and 24 per cent probability of the occurrence of moderate drought (Fig. 82). Lowest probability has been observed in Bobilli *mandal* of Vizianagaram district and highest probability has been observed in Chigurumamidi *mandal* of Karimnagar district (48%).

Around 80 per cent of the *mandals* in the state show a probability of < 2 per cent of occurrence of severe droughts. Probability of 2 to 6 per cent is noted in many *mandals* of Anantapur and Nalgonda districts (Fig. 83). Highest severe drought probability is seen in Y. Ramavaram (29%) and Pamarru (18%) *mandals* of East Godavari and Vemanapalli (15%) *mandal* of Adilabad.

4.12.1. Drought frequency based on Standardized Precipitation Index

Probabilities of occurrence of drought over Andhra Pradesh based on the IMD criteria (moderate and severe drought) have been discussed in the earlier section. However, number of drought indices (Deciles, Per cent Normal, Palmer Drought Severity Index have been used world-wide. Effective drought

Index has been suggested by Bhalme and Mooley (1981)[9] to classify the severity of droughts. Amongst different methods, Standardized precipitation index (SPI) is widely used. Main advantage of SPI is, that the rainfall is normalized using the probability distribution, so that values of SPI are actually related to standard deviation from the median. Drought probabilities for different *mandals* of Andhra Pradesh based on SPI methodology were computed for three time scales (Annual - 12 months scale, Southwest monsoon - 4 months scale and Northeast monsoon - 3 months scale) for 280 *mandals* for which daily rainfall data for 30 years or more is available. The criteria used in classifying drought severity using SPI values is given in Table 16. Drought event begins any time when the SPI is continuously negative and ends when the SPI gains a positive value.

Table 16: Categorization of climates based on SPI

SPI	Category
More than +2.0	Severely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to +0.99	Near Normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
Less than -2.0	Extremely dry

Thematic maps depicting probability levels for different drought severities for the selected three time scales are presented and discussed in the following sections.

4.12.2. Drought probability on annual scale

Probability for near normal condition of rain is above 50 per cent for all the 280 *mandals* considered for analysis. It is interesting to note that highest probability (83%) is observed in Penukonda *mandal* of Anantapur district followed by Suryapet *mandal* in Nalgonda district (80%) and Medchal *mandal* in Ranga Reddy district (80%). Though they are situated in arid and a semi-arid climatic region, near normal conditions is being expected over these *mandals*. In *mandals* from coastal Andhra region where annual rainfall is higher, the occurrence of near normal condition is less. Probability of 70 and above has been considered generally as a benchmark for making decisions on agricultural operations and this is observed in 112 *mandals* out of 280 *mandals* across the state for near normal condition (Fig. 84 a). Lowest probability for normal conditions is noted in Jammikunta *mandal* in Karimnagar district (52%) followed by Makthal in Mahabubnagar district (53%) and Kanigiri in Prakasam district (54%). Highest probability of occurrence for moderately dry condition is seen in Kanigiri in Prakasam district (21%) followed by 20 per cent probability in Chilamathur in Anantapur district, Gannavaram (Krishna district), Bobbili (Vizianagaram district), Kovvuru (West Godavari district) *mandals* (Fig. 84 b). It can be inferred that in 2 out of 10 years moderate dry conditions can be expected in the above *mandals*. Moderately dry conditions may not occur in Penukonda (Anantapur district), Madanapalli (Chittor district), Ipur and Sattanapalli (Guntur district), Mahabubnagar (Mahabubnagar district), Markapur (Prakasam district) and in Cherpurupalle (Vizianagaram district) *mandals*. The probability of occurrence of severe and extremely dry conditions is almost nil in 45 and 131 *mandals*, respectively. Highest probability (13%) under severe dry category has been noted in 7 *mandals* (Fig. 84 c) and extremely dry conditions may prevail with a 8% probability in Kodangal *mandal* of Mahabubnagar district (Fig. 84 d).

[9] Bhalme, H.N. and Mooley, D.A. 1981. Modification of Palmer drought index. IITM, Pune, 28p.

4.12.3. Drought probability during Southwest monsoon season

Probability for near normal condition during Southwest monsoon is above 50 per cent for all 280 *mandals*. Probability of 70% and above for near normal conditions has been noted in only one third of *mandals* of Andhra Pradesh (99 out of 280). However, the highest probability is observed in Pithapuram *mandal* (87%) in East Godavari district followed by Yellareddy in Nizamabad district (82%), Kowthalam in Kurnool district (82%) and Khanpur in Adilabad district (80%). Lowest probability of 51 per cent in Amarapuram (Anantapur district) and Sullurpeta (SPSR Nellore district) *mandals* has been recorded (Fig. 85 a). In the case of moderately dry category, highest probability of 20% and above noted in seven *mandals viz.,* Narpala, Sullurpeta (22%), Kanaganapalli, Peddapalli, Venkatapuram (21%), Nandigama and Darsi (20%) (Fig. 85 b). Very low probability for moderately dry condition to occur has been observed in Chennur (Adilabad district), Pithapuram (East Godavari district) and Kowthalam (Kurnool district) *mandals*. Like-wise, probability for severely and extremely dry condition to occur has been noted in 42 and 113 *mandals*, respectively (Fig. 85 c). However, probability of occurrence of severely dry conditions is highest (13%) in Kambadur and Kuderu *mandals* of Anantapur district and the probability of extremely dry condition is highest (8%) in Adoni *mandal* in Kurnool district followed by Chilamathur *mandal* of Anantapur district and Bhimadole *mandal* of West Godavari district (7%) (Fig. 85 d).

4.12.4. Drought probability during Northeast monsoon season

Probability for near normal conditions is above 50% during the northeast monsoon season in all the 280 *mandals* studied. Highest probability of 81 per cent has been noted in Baireddipalle *mandal* (Chittoor district) followed by 80 per cent in Srikalahasti *mandal* (Chittoor district) and Amalapuram *mandal* (East Godavari district) and lowest probability of 55 per cent observed in Peddapuram *mandal* (East Godavari district) and Gadivemula *mandal* (Kurnool district) (Fig. 86 a). *Mandals* in SPSR Nellore district which receive around 60 per cent of annual rainfall during this season, have a probability ranging from 56 per cent (Venkatagiri *mandal*) to 71 per cent (Atmakur *mandal*). These *mandals* receive near normal rainfall. Moderately dry condition can expected in 2 out of 10 years in Peddapuram *mandal* (East Godavari district) and Darsi *mandal* (Prakasam district) and the situation may not occur in Tirupathi *mandal* (Chittoor district), Sompeta *mandal* (Srikakulam district) and Bhimadole *mandal* (West Godavari district) (Fig. 86 b). Severely and extremely dry conditions were not noted in 29 *mandals* and 125 *mandals*, respectively. Highest probability (13%) for severely dry category has been observed in Huzurnagar *mandal* of Nalgonda district (Fig. 86 c) and extremely dry (8%) in Vinukonda *mandal* of Guntur district (Fig. 86 d).

4.13. Climatic Water balance

The term climatic water balance refers to balance obtained by comparing the precipitation as input with evapotranspiration as output. Water balance has been used for classification of climates, estimation of seepage from reservoirs, irrigation scheduling, designing of irrigation projects, forecasting river flows, and for stream flows, etc. For evaluation of the complete water balance of a location, it is necessary to compare precipitation (water supply) with potential evapotranspiration (water need) after making an allowance for the storage of water in the soil and its subsequent utilization for crop evapotranspirational purposes. The availability of water in right quantity at the right time and its management with suitable agronomic practices is essential for better crop growth and its yield. The water balance elements *viz.,* Precipitation (P), Potential evapotranspiration (PE), Actual evapotranspiration (AE), Water surplus (WS), Water deficit (WD) and also the water balance indices such as humidity index (Ih), aridity index (Ia) and Moisture Index (Im) for all *mandals* on an annual basis were estimated to calculate climatic water balance.

The water balance elements *viz.,* precipitation, potential evapotranspiration (PE), actual evapotranspiration (AE), water surplus (WS) and water deficit (WD) were computed by the revised book-keeping procedure of Thornthwaite and Mather (1955)[10]. The information on field capacity of the soil to hold the moisture for each station was extracted from Soils of India Series, published by NBSS & LUP, Nagpur.

Water balance indices such as humidity index (Ih) and aridity index (Ia) and moisture index (Im) were calculated using formulae:

1. Humidity index Ih = WS / PE X 100
2. Aridity index Ia = WD / PE X 100
3. Moisture Index Im = Ih - Ia

Based on Aridity index and Humidity index, the moisture index was calculated. Using moisture index (Table 17), *mandals* have been classified into different climatic types a and thematic map has been prepared. It is presented as Fig. 7 in section 1.3.

Table 17: Classification of climates according to the moisture index

Moisture Index Im (%)	Climate type (Symbol)
Above 100	Per-humid (A)
100 - 80	Humid (B4)
80 - 60	Humid (B3)
60 - 40	Humid (B2)
40 - 20	Humid (B1)
0 - 20	Moist Sub-humid (C2)
0 to – 33.3	Dry Sub-humid (C1)
-33.3 to - 66.7	Semi-arid (D)
Less than – 66.7	Arid (E)

Results presented in Fig. 7 indicate that 63 per cent of area of the State, is semi-arid. It is also evident from the water balance data that at least one or two *mandals* in each district are semi-arid. Majority of the *mandals* in Prakasam, Guntur and Krishna are semi-arid. All *mandals* in Anantapur district, majority of *mandals* in Mahabubnagar, Nalgonda, Kurnool and YSR Kadapa districts and Peddavedu *mandal* in Prakasam district experience arid climate accounting for 15% of the geographical area of the state.

Dry sub-humid climate, which is a transition between dry and moist tropical climates prevails over coastal districts like Visakhapatnam, East and West Godavari and many *mandals* of Vizianagaram, Srikakulam, SPSR Nellore and northern parts on Khammam and Warangal districts. These *mandals* accounts for 18% of the geographical area of the state. Among the coastal districts, entire Prakasam district is semi-arid. Though, majority of the *mandals* in Krishna, Guntur, Karimnagar and Adilabad have a semi-arid climate, few *mandals* are dry sub-humid climate. Moist sub-humid and humid B1 type climate is noted in Visakhapatnam district only. Munichigput is the only *mandal* having humid B1 climate with a highest annual rainfall in the state. In Visakhapatnam, Gudem Kothaveedhi and Gangarajau Madugula *mandals* are having a moist sub-humid climate.

It can be concluded from the above that 63% of the state experiences semi-arid climate, 18% (mostly in north coastal districts) has dry sub-humid and another 15% (Anantapur, Kurnool and YSR Kadapa) has an arid climate. Only one per cent of the area has a moist tropical climate.

[10] Thornthwaite, C.W. and Mather, J.R. 1955. The Water Balance. Publications in Climatology, Laboratory of Climatology, Vol.8, No.1, 104 pp.

4.14. Length of growing period (FAO method)

The Agro-Ecological Zones project of the Food and Agriculture Organization of the UN (FAO, 1978[11]) suggested a method to calculate LGP as the period (in days) during a year when precipitation exceeds half the potential evapotranspiration. Information on LGP helps in the selection of suitable crops, cropping systems, and crop cultivars. The length of the growing season (LGP) in any given region represents the climatically determined number of days during which a crop receives enough moisture for its growth. Potential evapotranspiration (PET) in the present study has been computed using ET_0 calculator (FAO, Penman-Monteith method). Monthly values for precipitation and PET were considered for computing LGP for all the *mandals*. Thematic map was prepared depicting the spatial distribution of LGP (Fig. 87).

Most of the state has LGP between 120-150 days. It covers districts of Adilabad, Nizamabad, Karimnagar, Medak, Warangal, Ranga Reddy, Khammam, Nalgonda, Mahabubnagar, Kurnool and Prakasam. LGP is > 180 days is observed in Srikakulam, Vizianagram, Visakhapatnam and parts of East and West Godavari, Chittoor and SPSR Nellore districts. It is in the range of 150 to 180 days in Krishna, Guntur, parts of Chittoor, SPSR Nellore, Khammam, East and West Godavari districts. The LGP is in the range of 90-120 days in parts of YSR Kadapa and Anantapur districts. However, in majority of the *mandals* of Anantapur district, the LGP is less than 90 days.

4.14.1. Start and end of growing season for different soil moisture holding capacities

Information on the start and end of rainy season aids in planning several field operations like land preparation and harvesting schedule. The difference between these two in days is the LGP. Apart from rainfall features like type of soil, soil depth, water holding capacity and moisture release characteristics of the soil as well as soil moisture storage at the end of the rainy season, the post-rainy season and winter rainfall, which can all meet the crop water needs determine the start and end of the growing season in each *mandal*. Weekly rainfall for all the *mandals* and PET estimated by ET_0 calculator for one representative station in each district was used to calculate Moisture Adequacy Index (MAI) through weekly water balance procedure for major soil groups having water holding capacities 50, 100, 150 and 200 mm in the root profile (Fig. 88 a to d). It is assumed that the season commences in a week after the 23rd SMW if the MAI value of two consecutive weeks is ≥ 0.5. Likewise, growing season is assumed to end if MAI is ≤0.25 for three consecutive weeks after 36th SMW.

4.14.2. Start of the growing season

The onset of monsoon determines the start of growing season but the soil type as an important role to play on the feasibility of sowing of crops due to differences in depth of wetting by rainfall and workability of soil. Therefore, the start of growing season in each *mandal* is computed and presented in Table 18 for four soil water holding capacities (50, 100, 150 and 200) (Fig. 89 a to d). In 8 out of 22 districts the season commences on an average during 25th SMW and in remaining districts the season commences during 26th to 29th SMW. A delayed commencement by 30th SMW is noted in SPSR Nellore, Prakasam and Anantapur districts.

4.14.3. End of the season

Growing season terminates early (by 42nd SMW) in Nalgonda district in soils having low water capacity (50 mm) and by 47th SMW in soils having a water holding capacity of 200 mm. Growing season terminates early in most of the *Telangana* districts (in 43 to 44 SMW) compared to coastal districts (in 46 to 48 SMW) (Fig. 90 a to d). Crop growing season extends by two weeks on an average with a corresponding increase in water holding capacity of the soil by 50 mm. In SPSR Nellore district, the crop growing season ends by 51st SMW in soils having 50 mm water holding capacity and by 8th SMW of the succeeding year in soils with a water holding capacity of 200 mm. On an average, the length of growing season is longest in coastal districts (22 weeks) followed by *Rayalaseema* (19 weeks) and

[11] FAO, 1978. Report on the agro-ecological zones projects. Vol.1: Results for Africa. World Soil Resources report 4811. FAO, Rome, 158 pp.

Table 18: Start, end and duration of crop growing season in soils with different water holding capacities in various districts of Andhra Pradesh

District	50 mm			100 mm			150 mm			200 mm		
	Start	End	Duration	Start	End	Duration	Start	End	Duration	Start	End	Duration
Adilabad	25	43	19	25	45	21	26	48	23	26	50	25
Anantapur	30	45	16	31	47	18	31	49	19	31	50	20
Chittor	29	50	22	29	1	25	29	3	27	29	5	28
YSR Kadapa	29	47	19	30	49	21	30	51	22	30	52	23
East Godavari	25	47	23	25	50	26	26	1	28	26	4	31
Guntur	28	47	20	28	50	24	28	1	26	28	4	29
Karimnagar	26	44	19	26	47	22	26	50	25	26	1	28
Khammam	25	44	19	25	46	22	26	48	24	26	50	26
Krishna	26	46	21	26	49	24	27	52	27	27	2	29
Kurnool	28	45	18	29	47	19	29	48	20	29	50	22
Mahabubnagar	28	43	16	28	43	16	28	47	19	28	48	21
Medak	26	44	18	27	46	20	27	49	23	27	51	25
Nalgonda	28	42	15	29	44	17	29	46	18	29	47	19
SPSR Nellore	30	51	22	29	2	26	29	3	29	29	8	31
Nizamabad	25	43	19	26	45	20	26	47	22	26	49	24
Prakasam	30	48	19	29	50	22	29	52	23	30	2	25
Ranga Reddy	27	45	19	27	47	21	27	50	24	28	1	26
Srikakulam	25	45	21	25	48	24	25	50	26	26	52	28
Visakhapatnam	25	47	23	25	51	26	25	2	29	26	6	33
Vizianagaram	25	48	25	25	52	28	25	3	31	26	7	34
Warangal	26	44	19	26	47	22	26	49	23	26	51	26
West Godavari	25	46	22	25	50	26	26	1	28	26	4	31

districts in *Telangana* (18 weeks) for soils having water holding capacity of 50 mm. The figures for soils having 100 mm capacity are 25, 21, 20, respectively. For soils having 150 mm water holding capacity the average duration for coastal, *Rayalaseema* and *Telangana* districts are 27, 22 and 22, respectively. In soils having 200 mm water holding capacity, the length of growing season on average for 30, 23 and 24 weeks in Coastal, *Rayalaseema* and *Telangana* districts, respectively.

4.15. Analysis of extreme weather events

RClimDex v 1.0 developed by WMO-CLIVAR was used to detect the trends in the occurrence of extreme rainfall, length of dry and wet spells using data from 1971 to 2011. Temporal homogeneity test was done to detect significant discontinuities or shifts in rainfall time series, using the software RHTestsV3 prior to using the data calculation of indices. A set of five indices were selected to analyze the rainfall behaviour *viz.*, the maximum one-day rainfall, maximum five-day rainfall, daily rainfall intensity, maximum length of dry spell and maximum length of wet spells. The data, as in the case of SPI, are analyzed for a period exceeding 30 years for 280 *mandals* and hence the trends were computed for these *mandals*. The geospatial maps were prepared based on these data points by interpolation.

4.15.1. Episodes of maximum one-day rainfall

Results presented in Figure 91 show that no significant increasing or decreasing trend is noticed in majority of *mandals* (220 out of 280 *mandals*) regarding maximum one-day rainfall. An increasing trend is observed in 30 *mandals* only. These are located in Krishna district (8 *mandals*) followed by Visakhapatnam (4 *mandals*) and Khammam (3 *mandals*). Declining trend is noted in 30 *mandal*s with highest number of *mandals* located in Chittoor district (7 *mandals*) followed by Anantapur district (6 *mandals*), Kurnool and Vizianagaram (3 *mandals*) districts. It may be concluded that high daily rainfall episodes show an increasing trend mainly over the Coastal Andhra region followed by the *Telangana* region while a declining trend is noted over the *Rayalaseema* region.

4.15.2. Trends in maximum cumulative amount of five-day rainfall events across different *mandals* in Andhra Pradesh

A significant increasing trend in maximum 5-day cumulative rainfall has been noted in eight *mandals viz.*, Piler (Chittoor), Avanigadda, Vijayawada - Urban (Krishna), Gudur, Kurnool, Srisailam (Kurnool), Visakhapatnam (Visakhapatnam) and Denkada (Vizianagaram) *mandals* (Fig. 92). A declining trend is observed in Satyaveedu (Chittoor) and in Gundala (Khammam) *mandals* only.

4.15.3 Trends in mean daily rainfall intensity

Mean one-day amount of rain is calculated by dividing the annual rainfall by the number of wet days (rainfall > 1 mm) in each year. Out of 280 *mandals* analyzed only 16 showed increasing tendency in mean daily rainfall intensity. On the other hand only two *mandals viz.*, Piduguralla (Guntur) and Gajapathinagaram (Vizianagaram) *mandals* showed a declining trend (Fig. 93).

4.15.4. Trends in maximum length of dry spell during the SWM rainy season

The length of dry spell during crop growing season determines quality as well as the productivity of crops. No significant increasing or declining trend has been noted in 93 per cent (260 out of 280 *mandals*) analyzed. However, an increasing trend has been evident in six *mandals* out of which three are located in East Godavari district (Peddapuram, Ramachandrapuram, Rampachodapuram) and one each in Mahabubnagar (Achampet), Prakasam (Darsi) and Vizianagaram (Gajapatinagaram) districts. On the other hand, a declining trend is observed in the length of dry spell in 14 *mandals* out of which 10 *mandals* are located in the *Rayalaseema* region (Fig. 94). Thus, it can be inferred that increasing / decreasing trend in length of dry spell has occurred in very few pockets spread across the state, but a decreasing trend is evident in sufficient number of *mandals* of the *Rayalaseema* region. This is a welcoming feature of the temporal distribution of rainfall considering the rainfall variability in this region.

4.15.5. Trends in maximum length of wet spell during rainy season in Andhra Pradesh

There is no significant increasing or decreasing trend noted in the length of continuous wet spells in 90 per cent, 250 out of 280 *mandals* in the state (Fig. 95). The length of wet spells showed an increasing trend in 22 *mandals* out of which 13 *mandals* are located in the Coastal Andhra region and 9 *mandals* are situated in the Rayalaseeema region. A declining trend is observed only in 8 *mandals viz.,* Addateegala (East Godavari), Gundala (Khammam), Allagadda (Kurnool), Kodangal (Mahabubnagar), Nadigudam (Nalgonda), Medchal (Ranga Reddy), Narsampet (Warangal) and Chintalapudi (West Godavari) *mandals*.

4.16. Extreme events recorded in Andhra Pradesh

The recorded extreme events for Andhra Pradesh in respect of rainfall and temperature as per the records available are sourced from IMD website http://imdhyderabad.gov.in/extwx.htm and presented in Table 19. Highest known rainfall event of 675 mm occurred on 17th June 1996 at Koida in Khammam district linked to a cyclone storm during 12th - 16th June, 1996. The second highest rainfall event of 523.4 mm was recorded at SPSR Nellore on 03rd November, 1987. This event was associated with a cyclonic storm which was active during October 31 to November 3, 1987 over Bay of Bengal. Highest maximum temperature ever recorded was 48.8°C on 11th May, 2002 at Gannavaram followed by 48.6°C at Bhadrachalam on 05th May, 1973. Lowest minimum temperature was recorded 4.4°C on 17th December, 1897 at Nizamabad followed by 5.2 on 26th January, 2006 at Adilabad.

Table 19: Ever recorded extreme values in Andhra Pradesh updated up to December 2012

District / Station	Datum period	Date	Maximum Temp. (°C)	Date	Minimum Temp. (°C)	Date	Highest rain-fall recorded in 24 hrs period (mm)
Adilabad	1980-Dec. 2012	05-06-1995	46.8	26-01-2006	5.2	20-10-1995	252
Arogyavaram	May 1946-Dec. 2012	02-06-2003	40.6	11-01-2008	8.0	22-10-1954	158
Anantapur	Aug. 1910-Dec. 2012	20-05-2005	44.1	23-12-2010	9.4	19-08-1932	311
Bapatla	1978- Dec. 2012	31-05-2003	47.4	07-01-1992	11.6	22-06-2007	251
Bhadrachalam	Jan. 1952-Dec. 2012	09-05-1973	48.6	05-01-1962 & 11-12-1970	8.4	20-09-2005	231
Kalingapatnam	July 1906-Dec. 2012	20-05-1978	46.9	14-01-2012	9.5	19-09-2005	355
CWC Visakhapatnam	June 1963-Dec. 2012	13-05-2002	45.0	08-01-1972	12.4	17-10-1982	371
Visakhapatnam	Jan. 1970-Dec. 2012	09-06-1995	45.4	06-01-1962 & 07-01-1962	10.5	20-10-1958	293
Gannavaram	Mar. 1945-Dec. 2012	11-05-2002	48.8	07-01-1992	11.1	23-07-1989	211
Hanamakonda	Jan. 1898-Dec. 2012	03-06-2003	47.8	29-12-1902	8.3	28-09-1908	305
Hyderabad	Nov. 1891-Dec. 2012	02-06-1966	45.5	08-01-1946	6.1	24-08-2000	242
YSR Kadapa	Apr. 1884-Dec. 2012	18-05-1906	46.1	08-01-1992	10.0	08-10-1958	270
Kakinada	Apr. 1880-Dec. 2012	08-06-1923	47.2	06-01-1962	12.0	02-06-1941	501

District / Station	Datum period	Date	Maximum Temp. (°C)	Date	Minimum Temp. (°C)	Date	Highest rain-fall recorded in 24 hrs period (mm)
Kavali	Feb. 1995-Dec. 2012	31-05-2003	47.2	25-01-2006	16.9	30-10-2007	355
Khammam	Dec. 1940-Dec. 2012	25-05-1947	47.2	08-01-1946	9.4	10-07-1954	300
Koida, Khammam						17-06-1996	675
Kurnool	Jan. 1883-Dec. 2012	10-05-1921 & 02-06-1998	45.6	29-12-1902	6.7	23-06-2007	394
Machlipatnam	Aug. 1868-Dec. 2012	25-05-1906 & 31-05-2003	47.8	01-12-1970	13.2	28-10-1949	502
Mahabubnagar	Feb. 1952-Dec. 2012	30-04-1973	45.3	16-01-2009	9.1	15-08-1978	252
Medak	1979- Dec. 2012	18-05-2006	46.3	11-12-1981	6.9	21-09-2005	192
Nalgonda	1977- Dec. 2012	02-06-1998	46.3	22-12-2010	10.6	04-11-1987	164
Nandigama	Mar. 1987-Dec. 2012	31-05-2003	47.1	15.01.2012	8.9	23-07-1989	182
Narsaraopet	1980- Dec. 2012	02-06-1983 & 03-06-1983	47.0	29-11-1981	13.2	20-10-1982	170
Nandyal	1966- Dec. 2012	14-04-1981	46.1	04-01-1971	9.2	23-08-2000	377
Narsapur	Mar. 1988-Dec. 2012	31-05-1998	46.1	15.01.2012	13.5	23-07-1989	254
SPSR Nellore	Sep. 1888-Dec. 2012	15-05-1892 & 01-06-1894	46.7	10-12-1895 & 07-01-1962	14.4	03-11-1987	523
Nidadavolu	Oct. 1955-Dec. 2012	10-05-1973	47.0	22-02-1993	11.4	23-07-1989	390
Nizamabad	Nov. 1891-Dec. 2012	22-05-2005	47.3	17-12-1897	4.4	06-10-1983	355
Ongole	Aug. 1944-Dec. 2012	31-05-2003	47.4	06-01-1962	14.0	20.-05-2010	324
Ramagundam	1946- Dec. 2012	24-05-1984	47.3	14.01.2012	6.8	05-08-2006	216
Rentachintala	Feb. 1936-Dec. 2012	23-05-2002	48.3	08-02-2004	9.4	29-09-1964	227
Tirupati ap	June 1983-Dec. 2012	02-06-2003	45.2	07-01-1992	12.9	23-11-2005	211
Tuni	May 1995-Dec. 2012	30-05-1998	47.5	15.01.2012	12.6	17-06-1996	196
Vijayawada	1979- Dec. 2012	26-05-1980	47.5	26-11-1981	14.0	18-10-80	98
Dolphin nose point, Visakhapatnam	1973- Dec. 2012	02-06-1984	44.0	12-01-1981 & 16-01-1986	15.6	17-10-1982	426

(After: http://imdhyderabad.gov.in/extwx.htm)

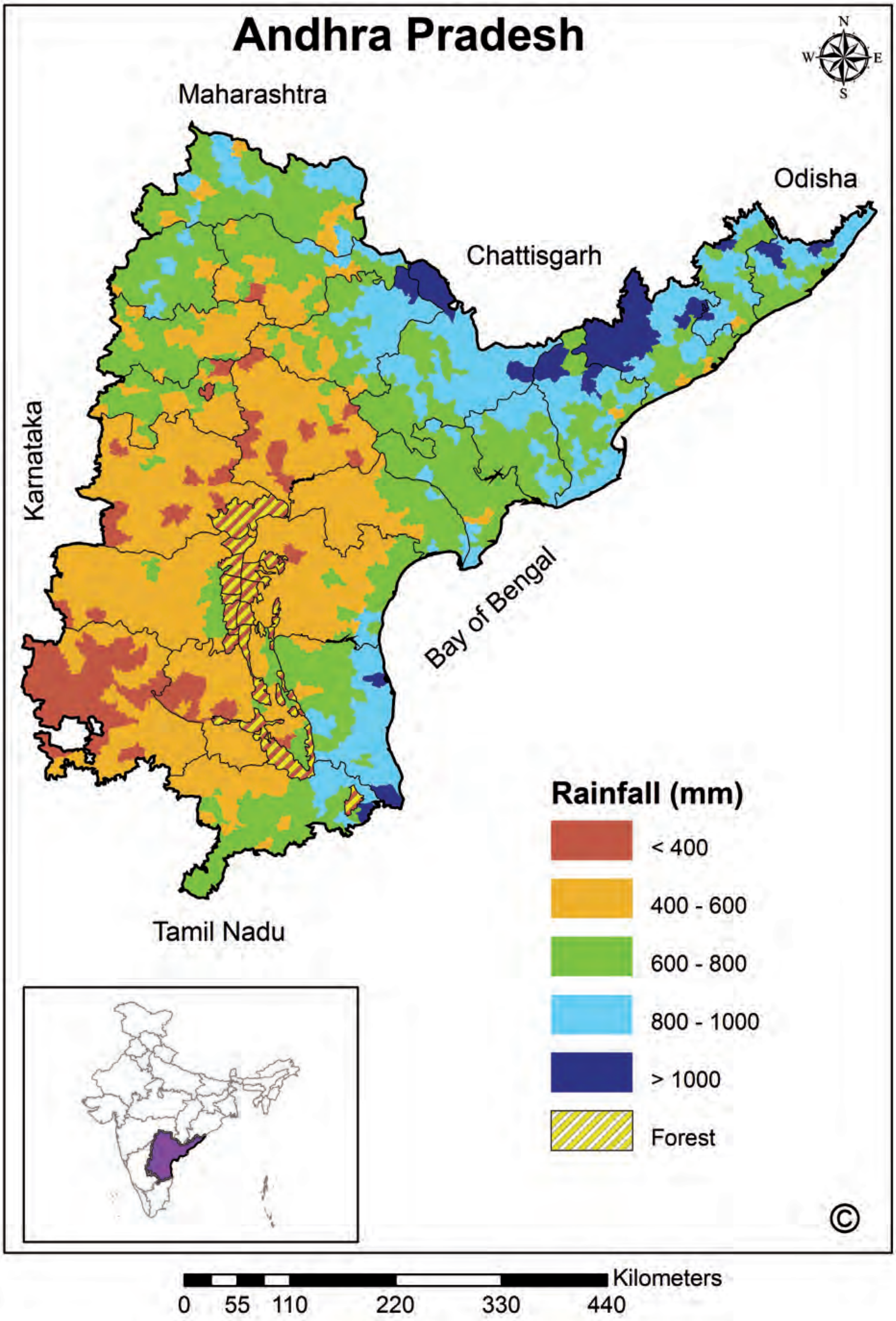


Fig. 68: Area with ≥ 75% probable annual rain in Andhra Pradesh

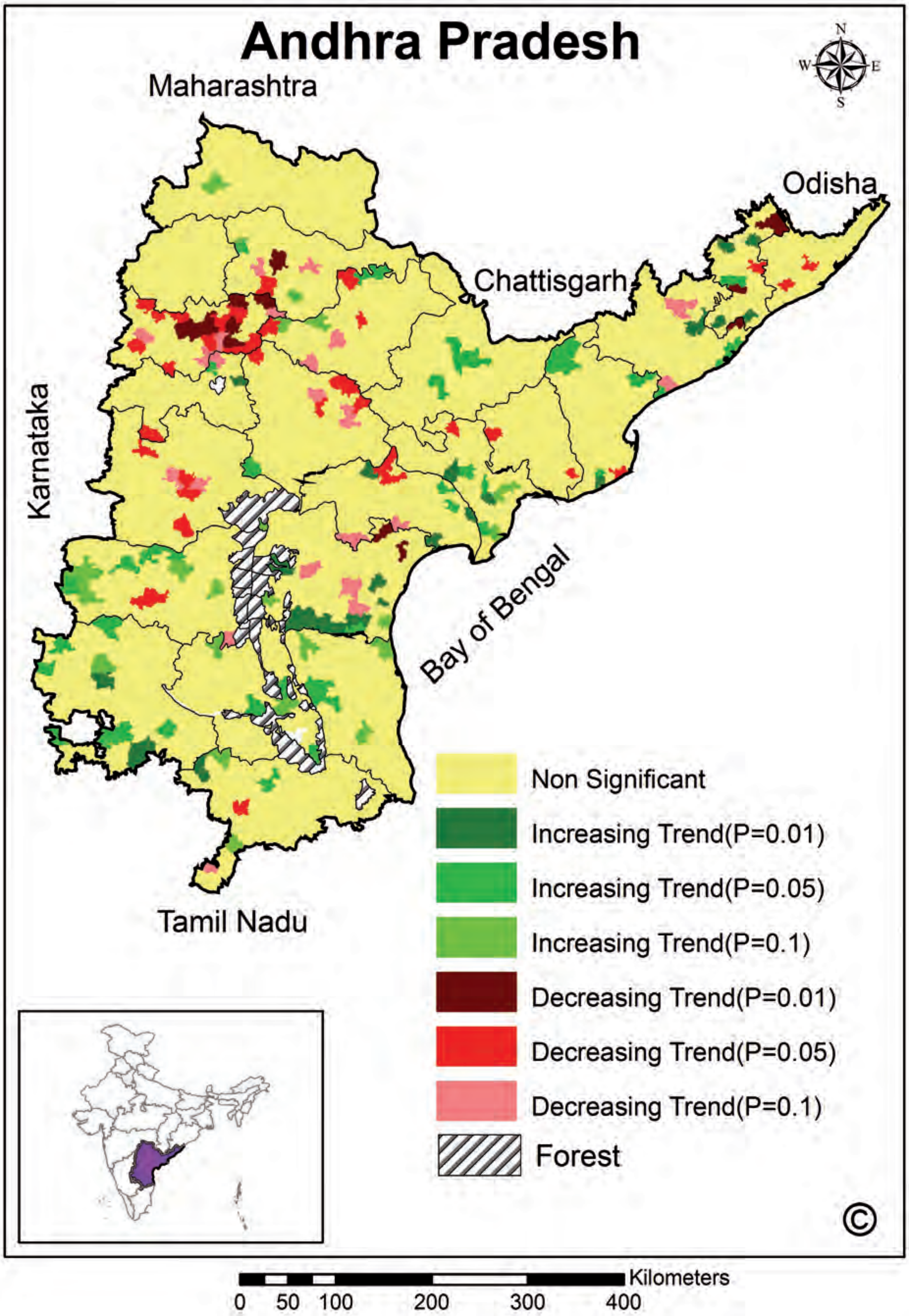


Fig. 69: *Mandals* in Andhra Pradesh showing a change in the annual rainfall pattern

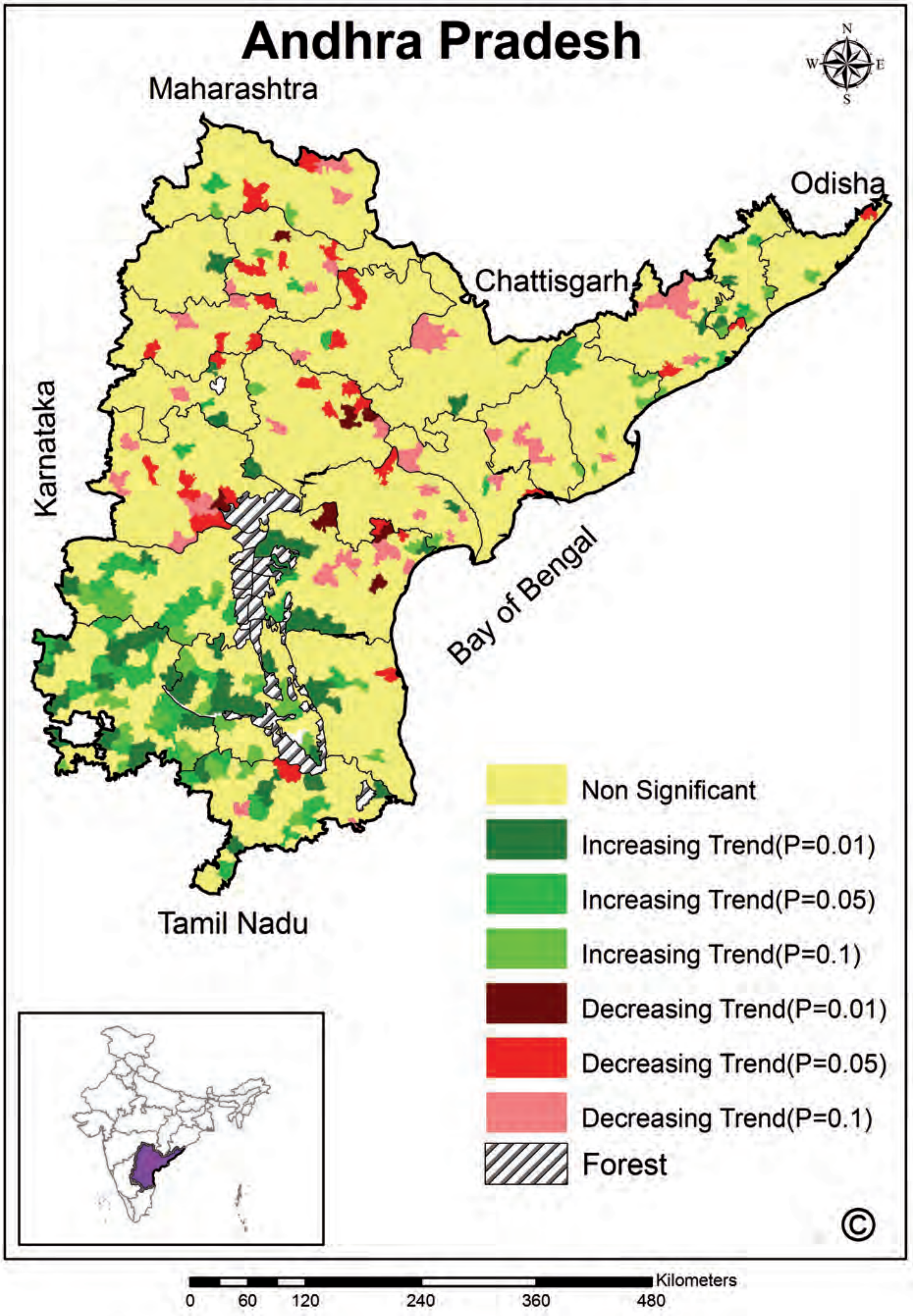


Fig. 70: *Mandals* in Andhra Pradesh showing a change in the annual rainy days pattern

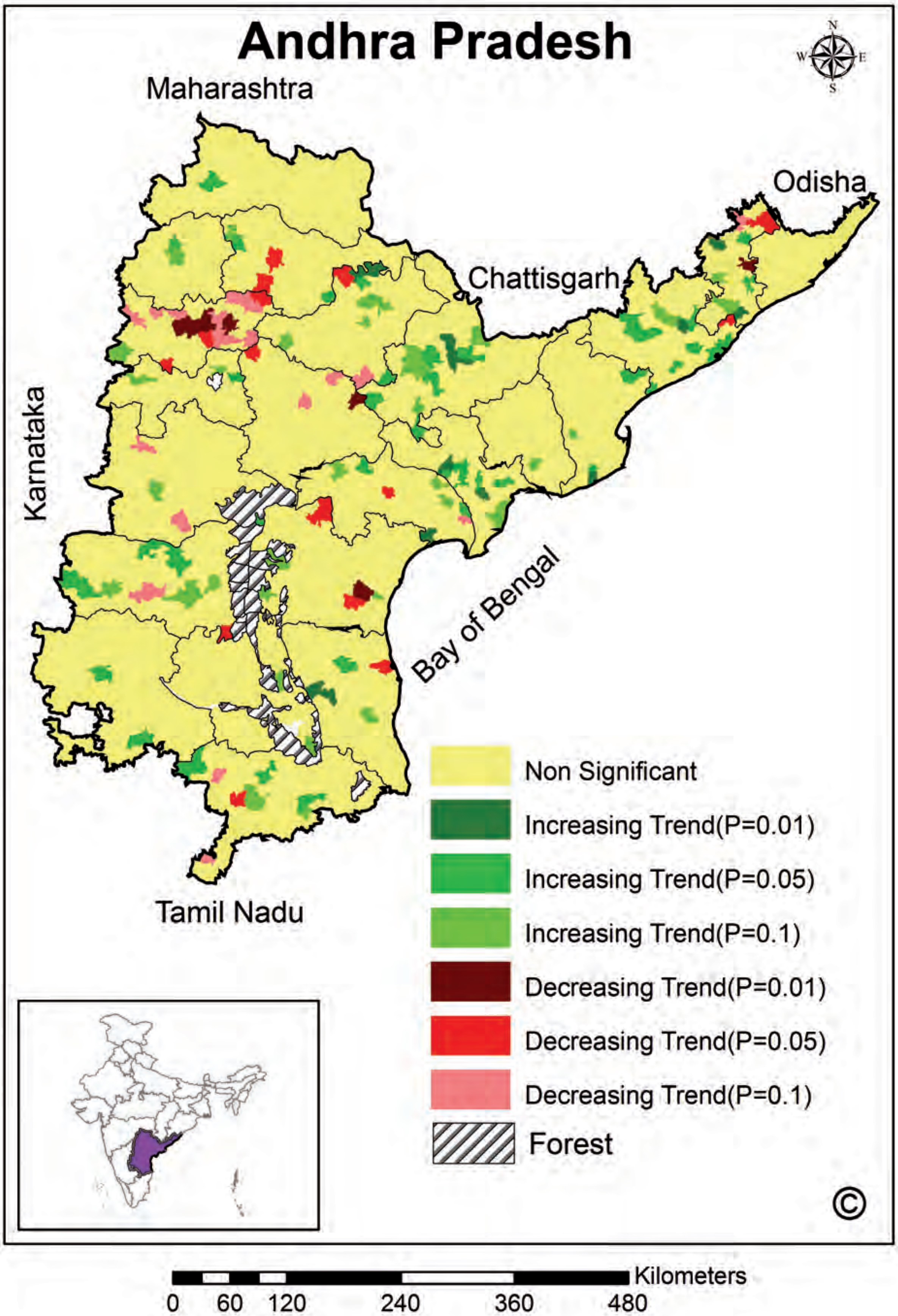


Fig. 71: *Mandals* in Andhra Pradesh showing a change in the southwest monsoon season rainfall pattern

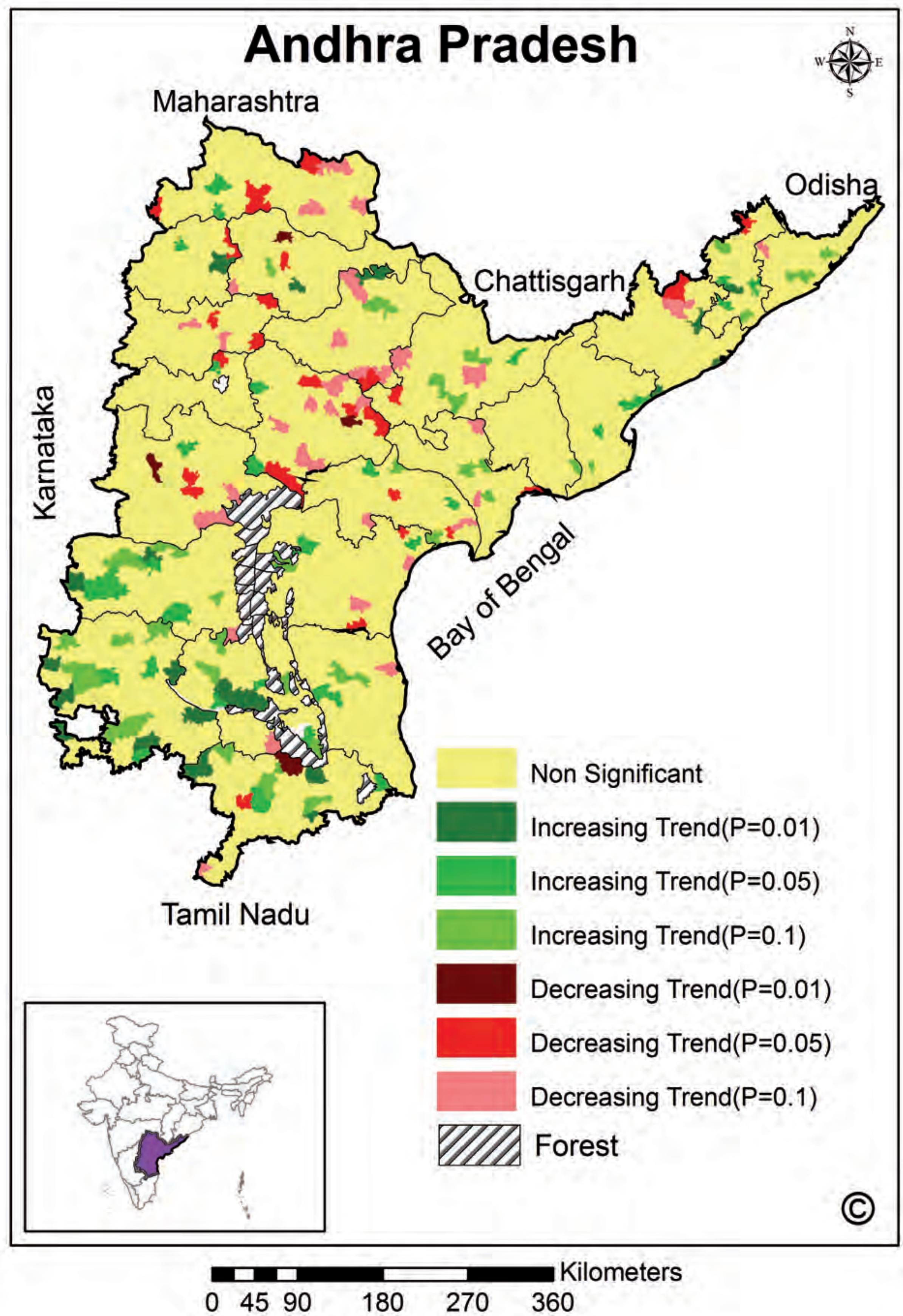


Fig. 72: *Mandals* in Andhra Pradesh showing a change in the number of rainy days pattern during Southwest monsoon season

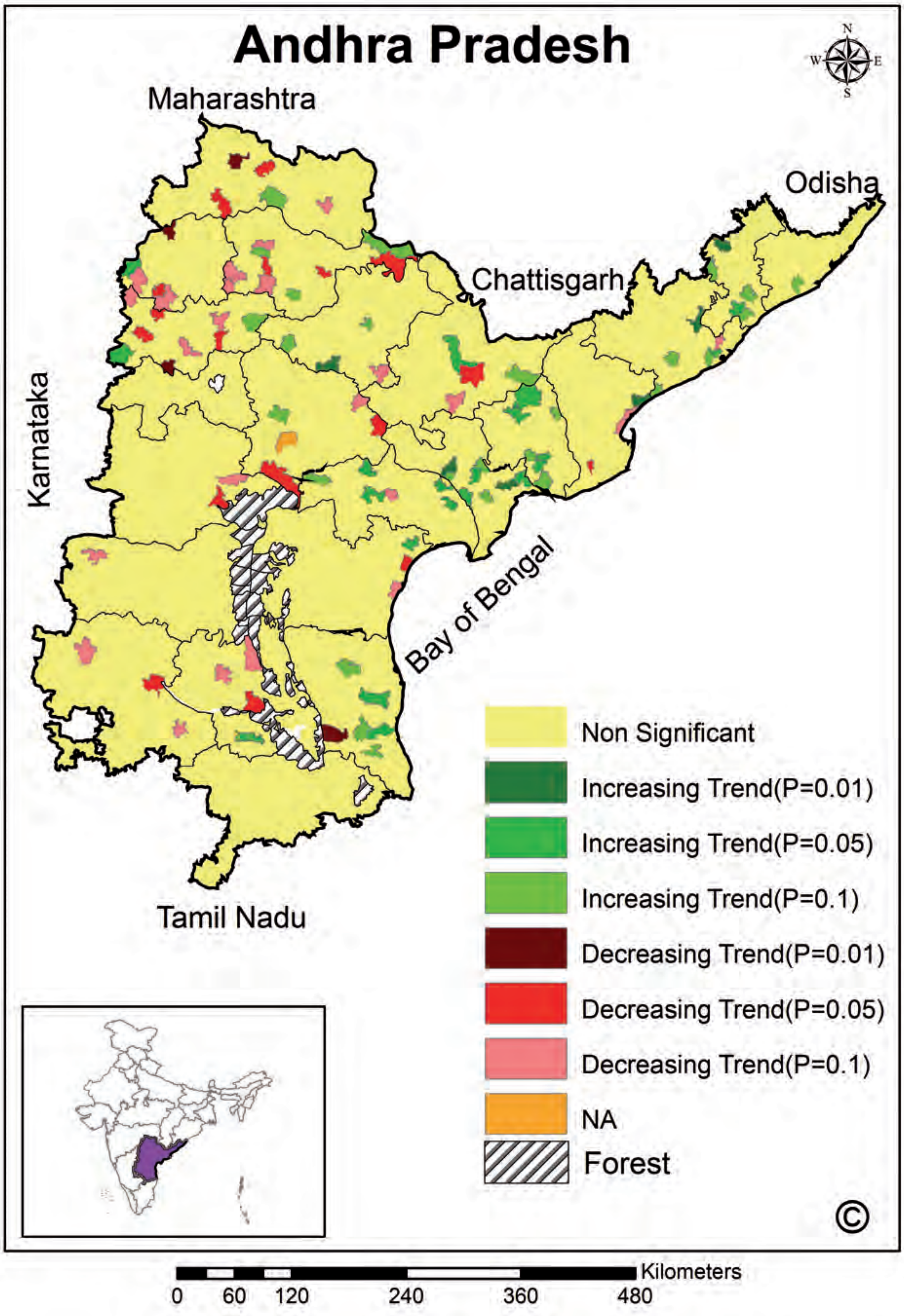


Fig. 73: *Mandals* in Andhra Pradesh showing changes in annual rainfall events in the 75-100 mm category

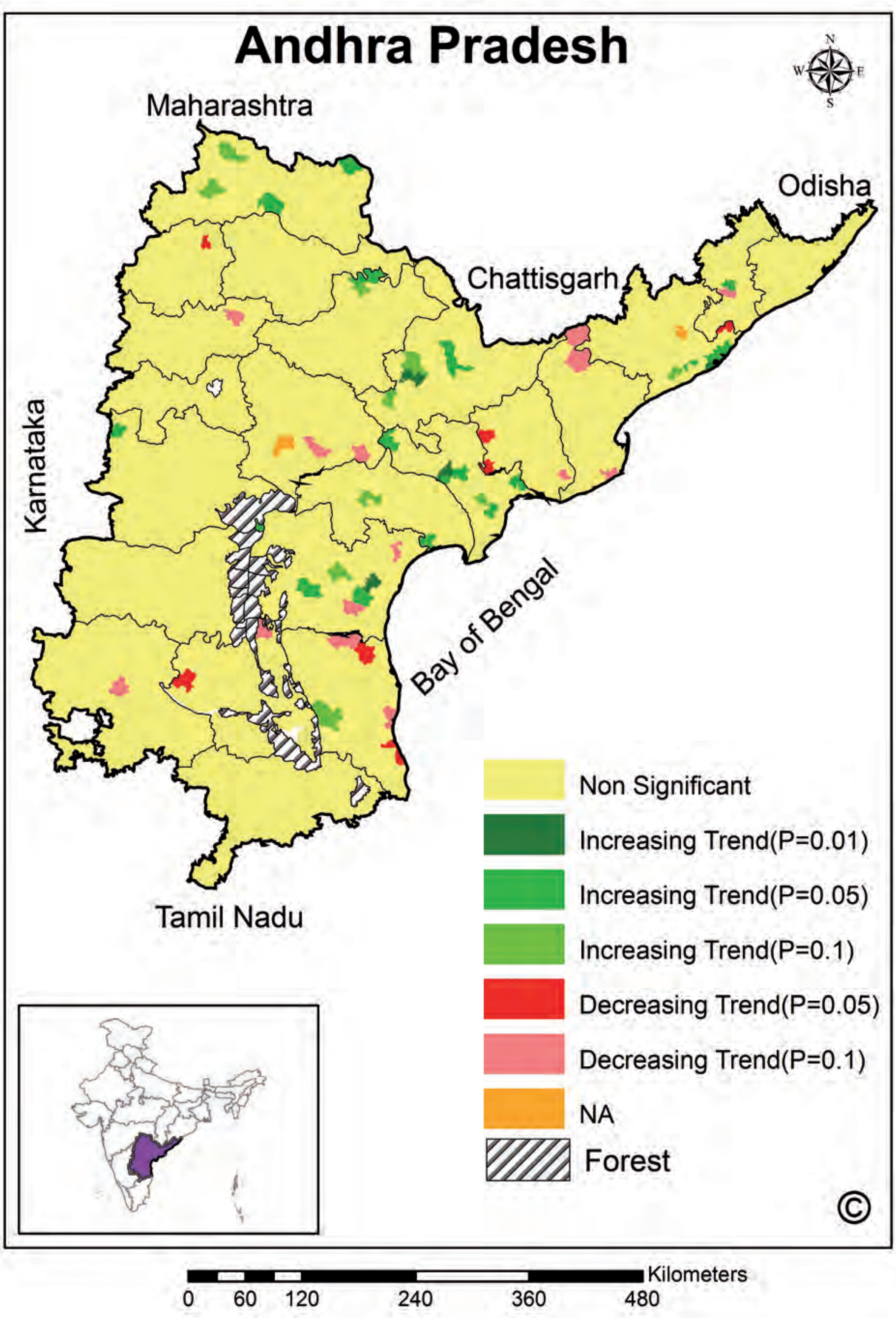


Fig. 74: *Mandals* in Andhra Pradesh showing changes in annual rainfall events in the >100 mm category

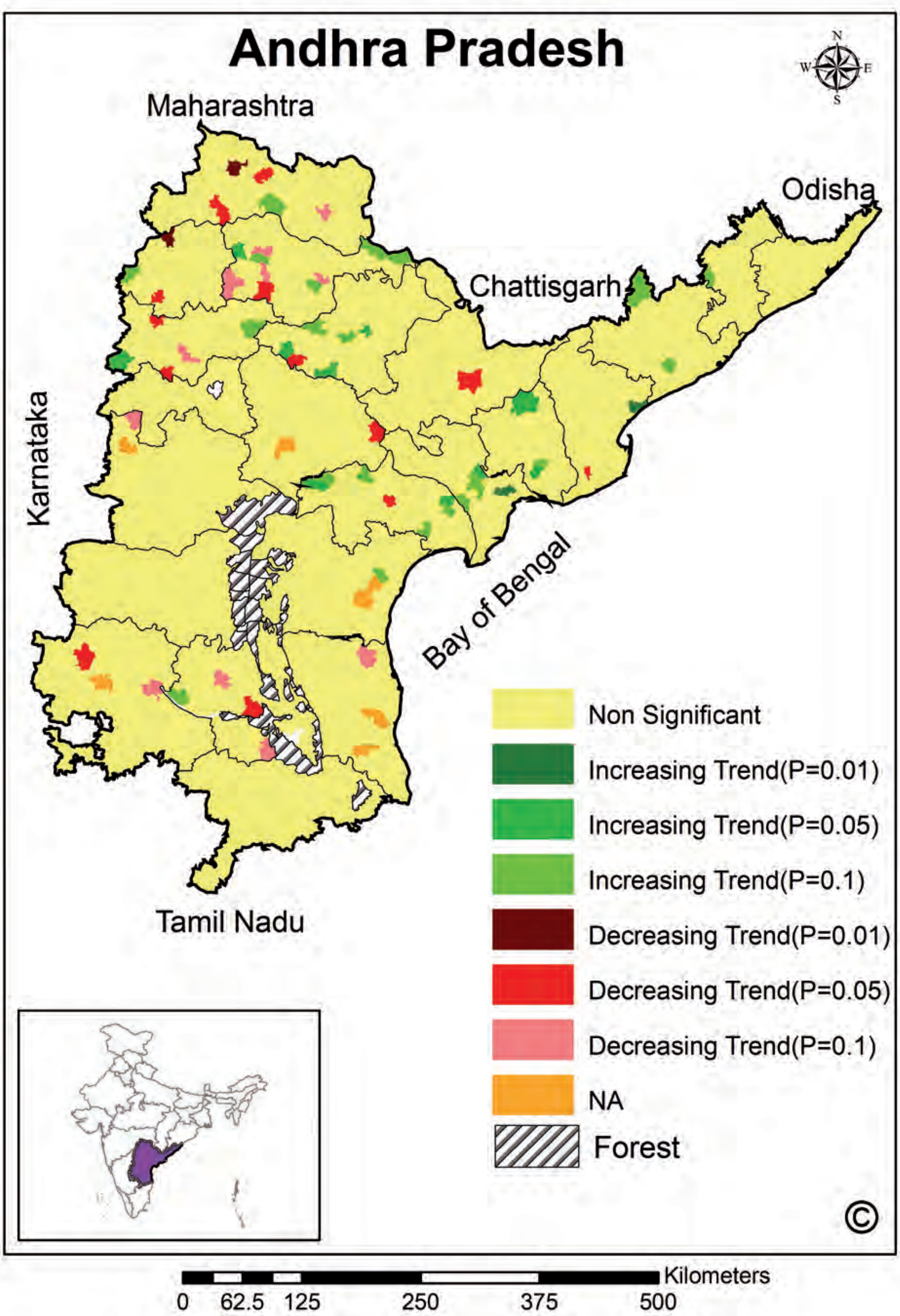


Fig. 75: *Mandals* in Andhra Pradesh showing changes in Southwest monsoon rainfall events in the 75-100 mm category

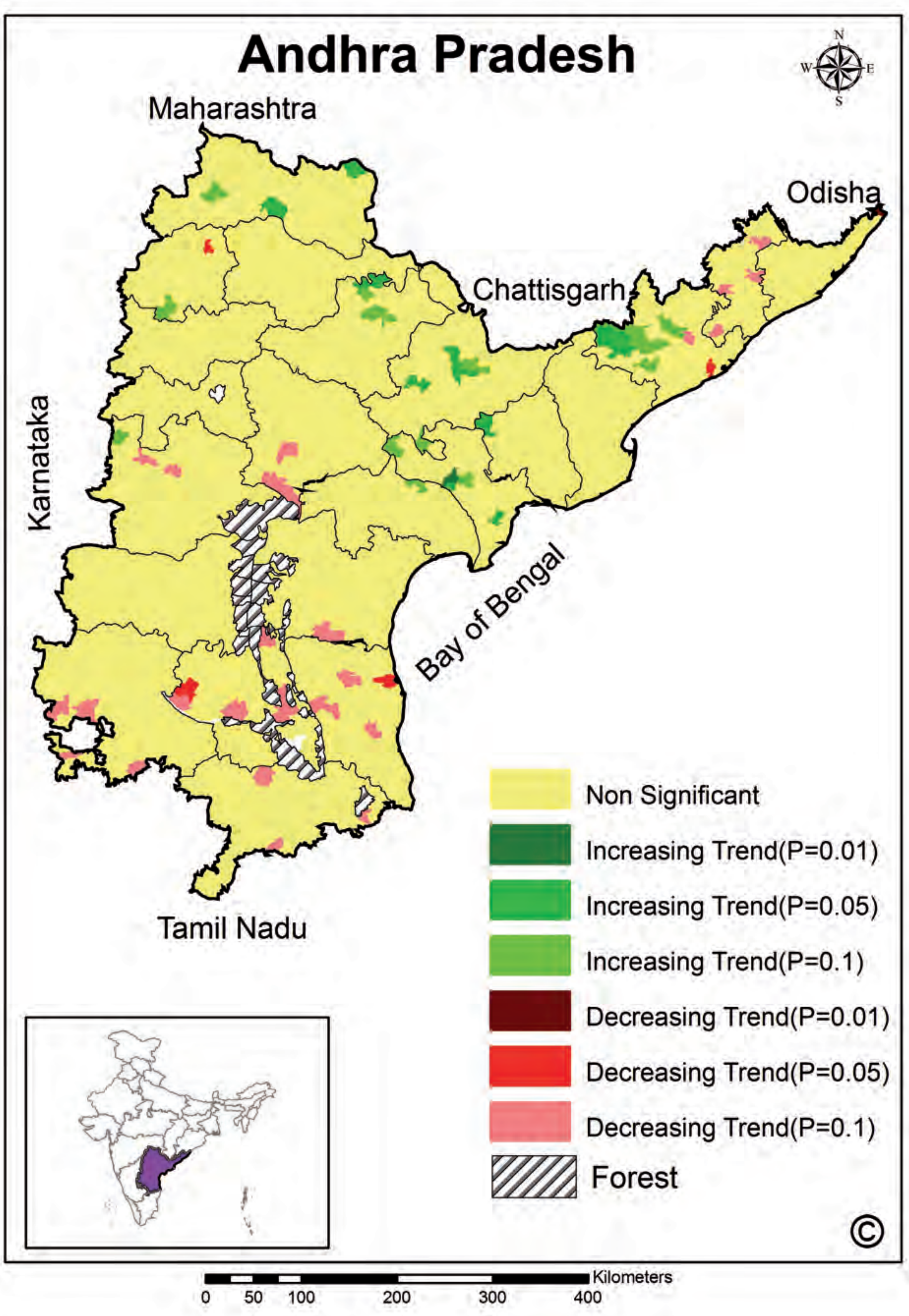


Fig. 76: *Mandals* in Andhra Pradesh showing changes in Southwest monsoon rain events in the >100 mm category

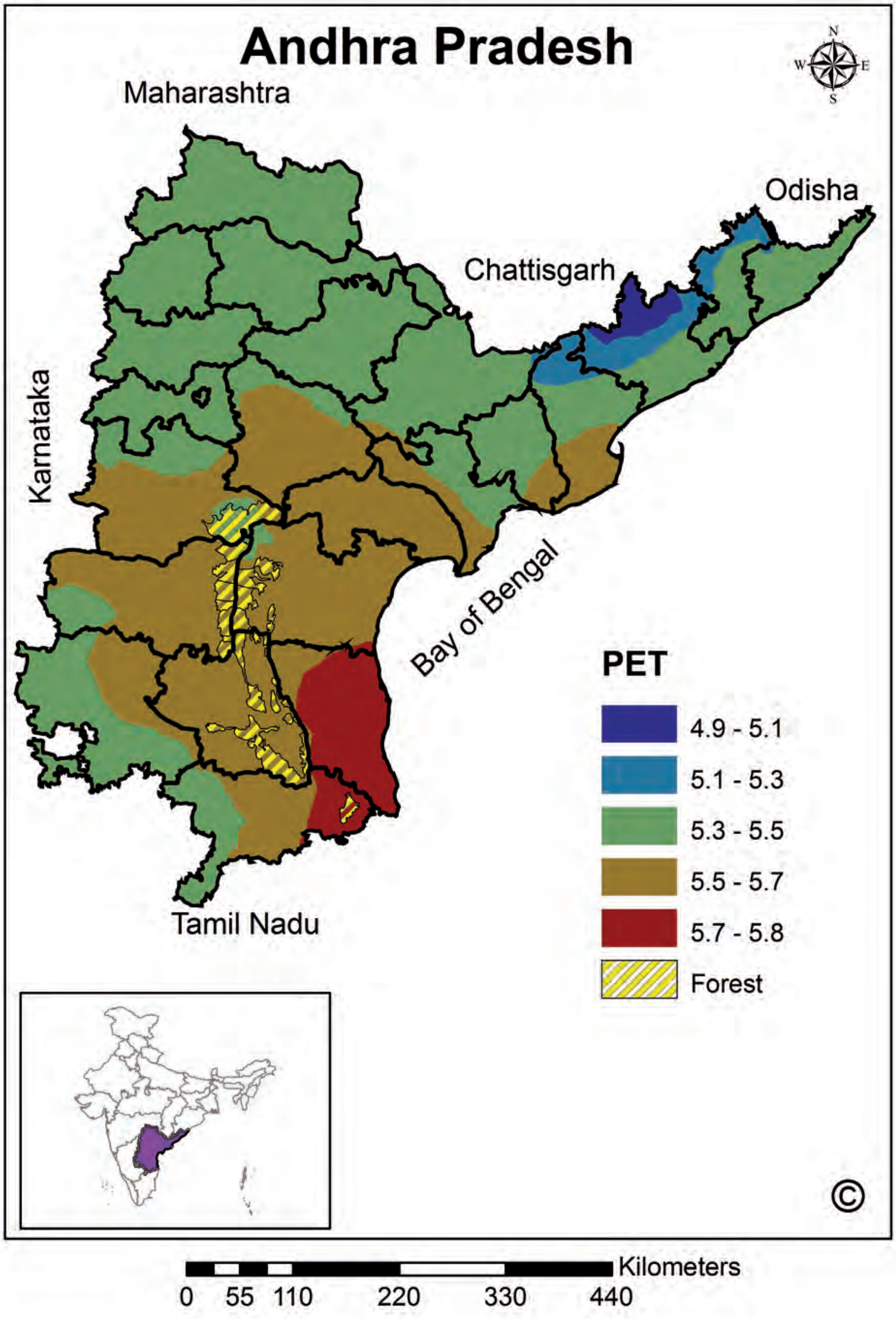


Fig. 77: Annual potential evapotranspiration (mm/day) over Andhra Pradesh

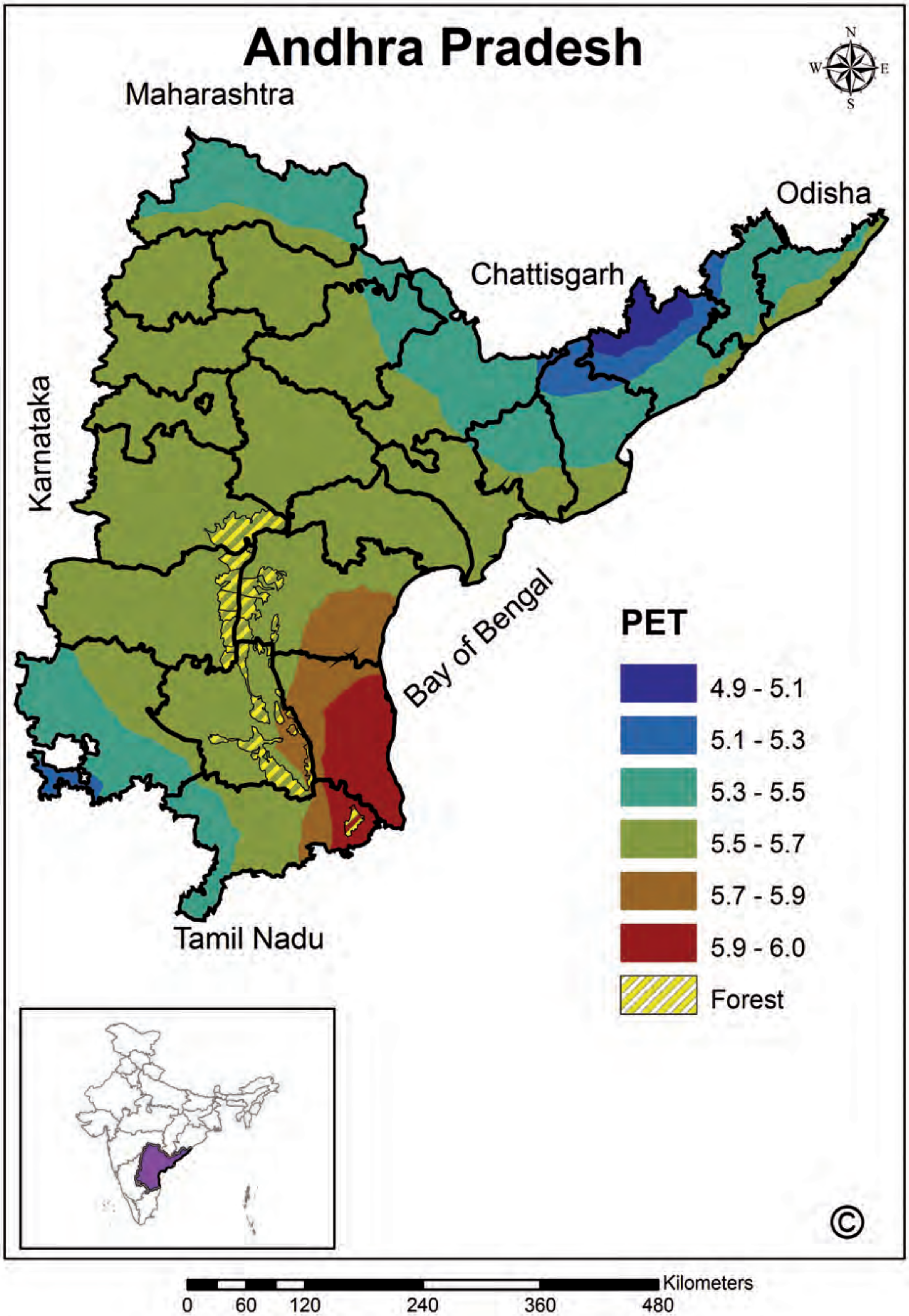


Fig. 78: Southwest monsoon season potential evapotranspiration (mm/day) over Andhra Pradesh

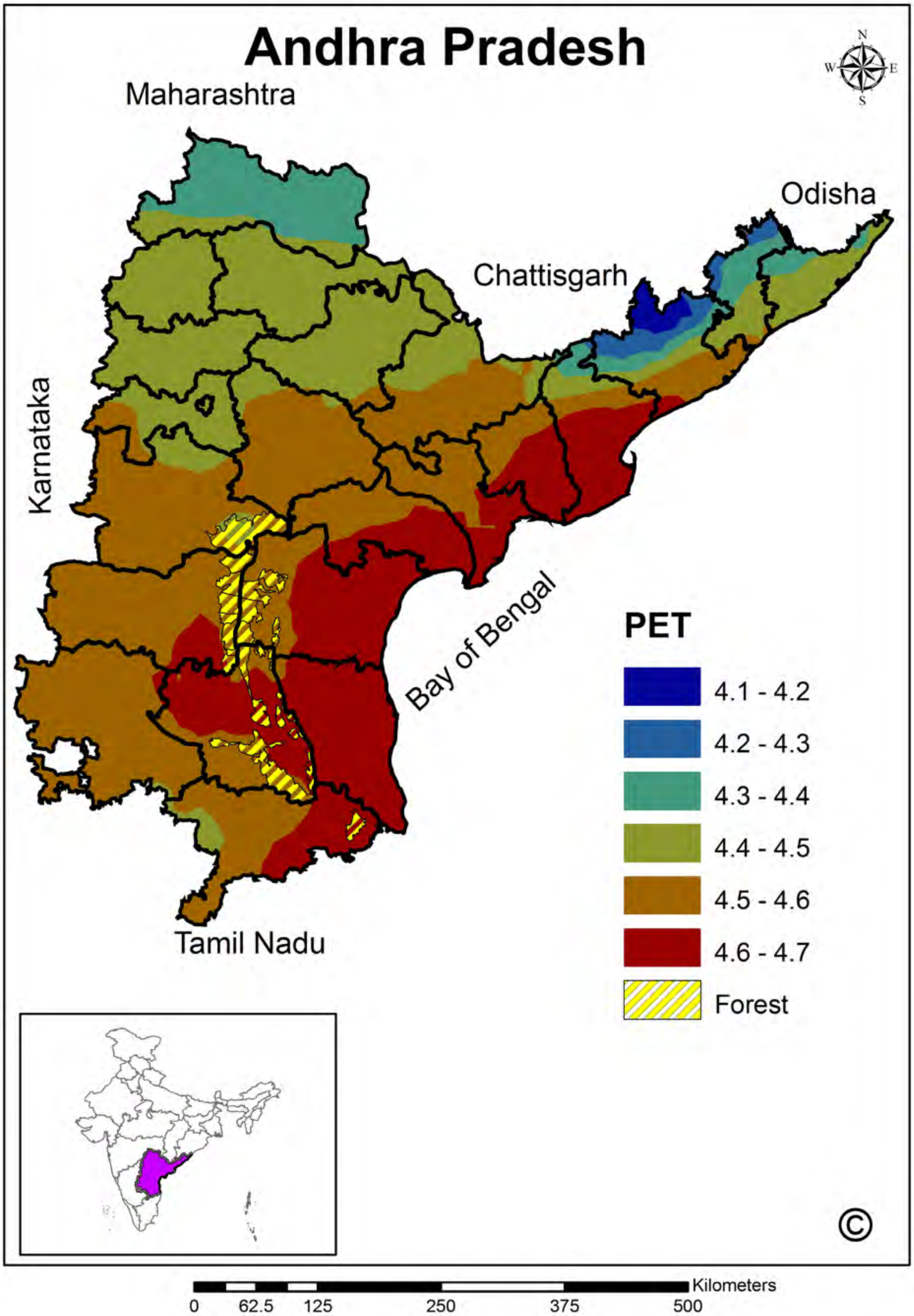


Fig. 79: Northeast monsoon season potential evapotranspiration (mm/day) over Andhra Pradesh

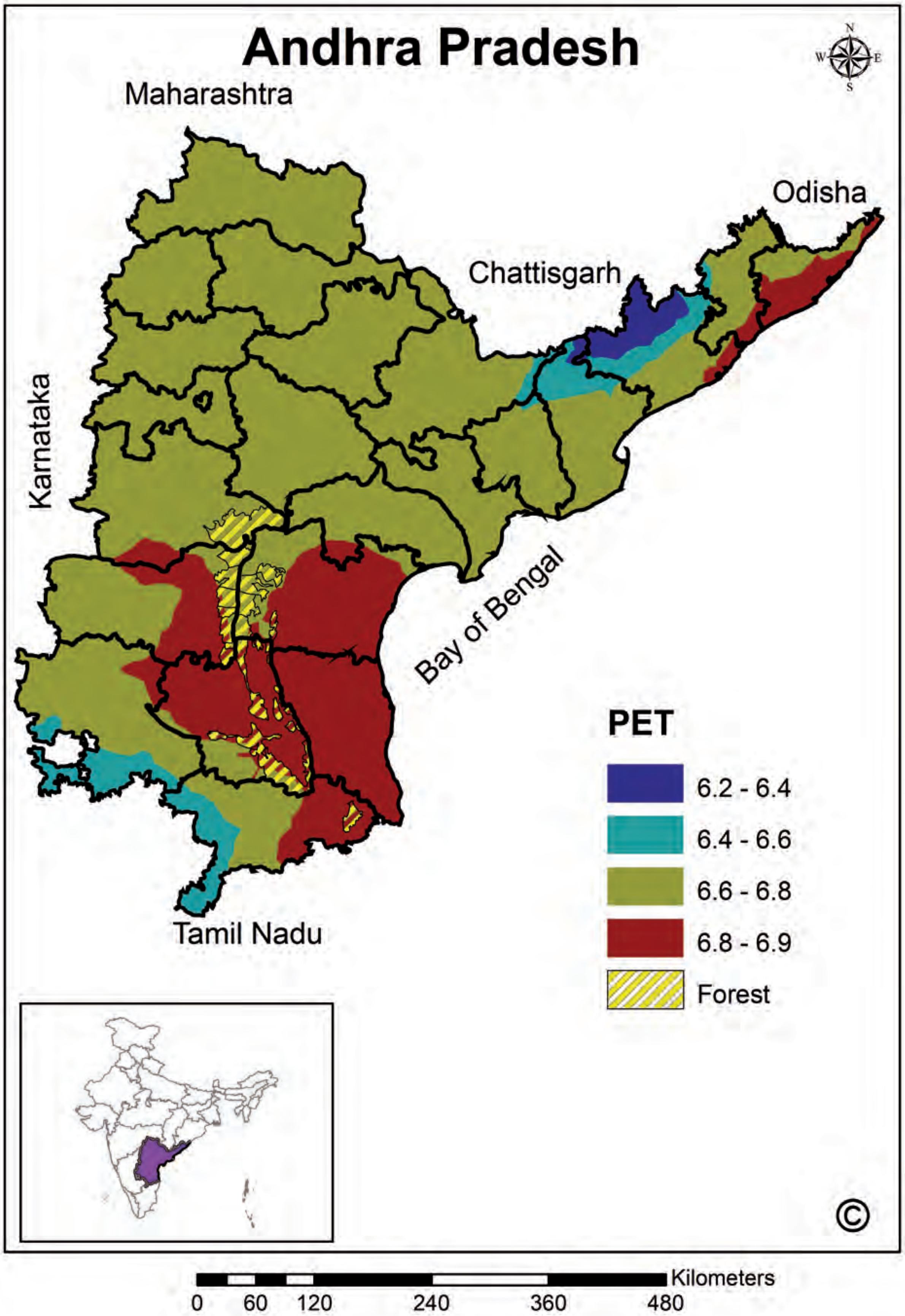


Fig. 80: Summer season potential evapotranspiration (mm/day) over Andhra Pradesh

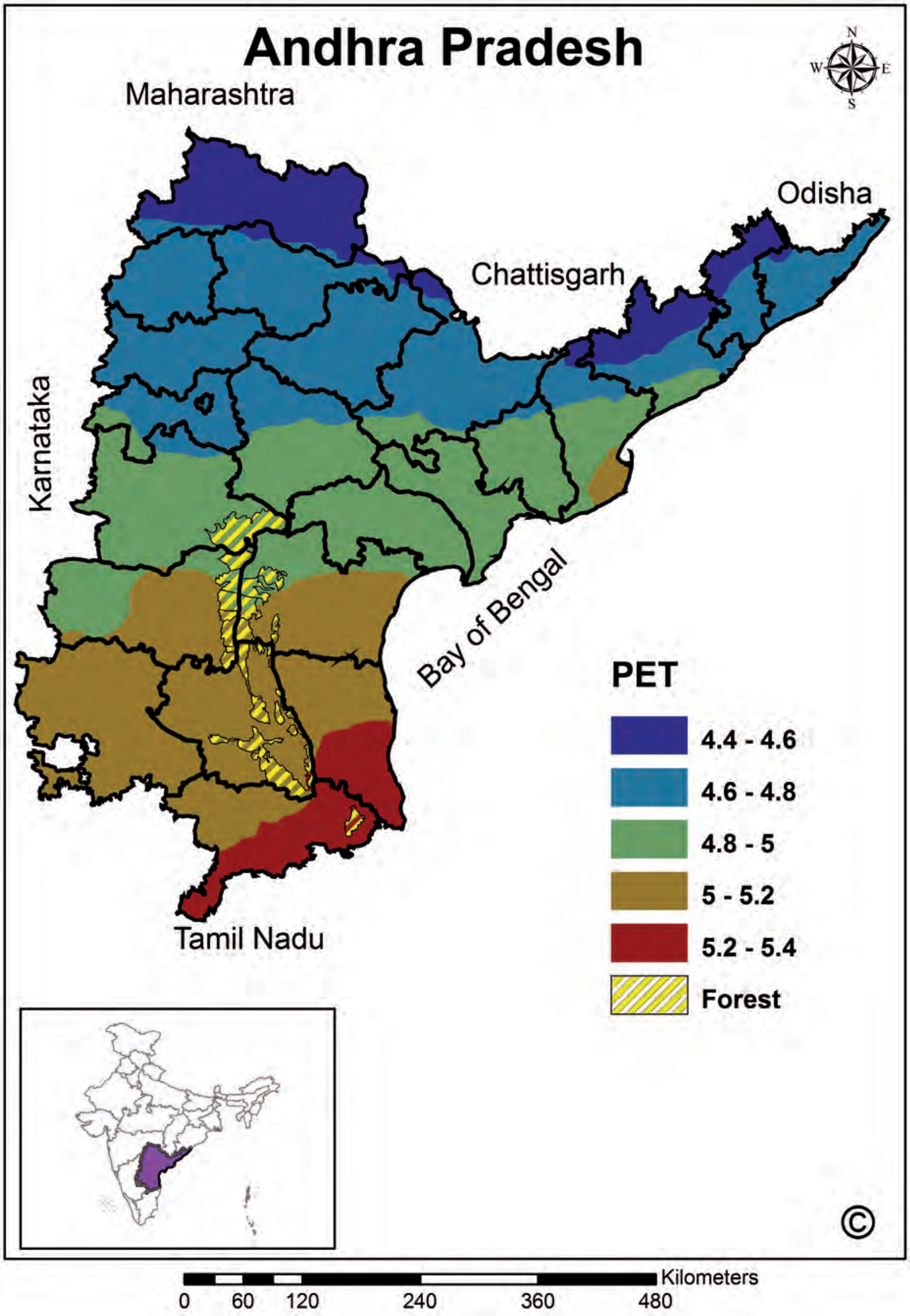


Fig. 81: Winter season potential evapotranspiration (mm/day) over Andhra Pradesh

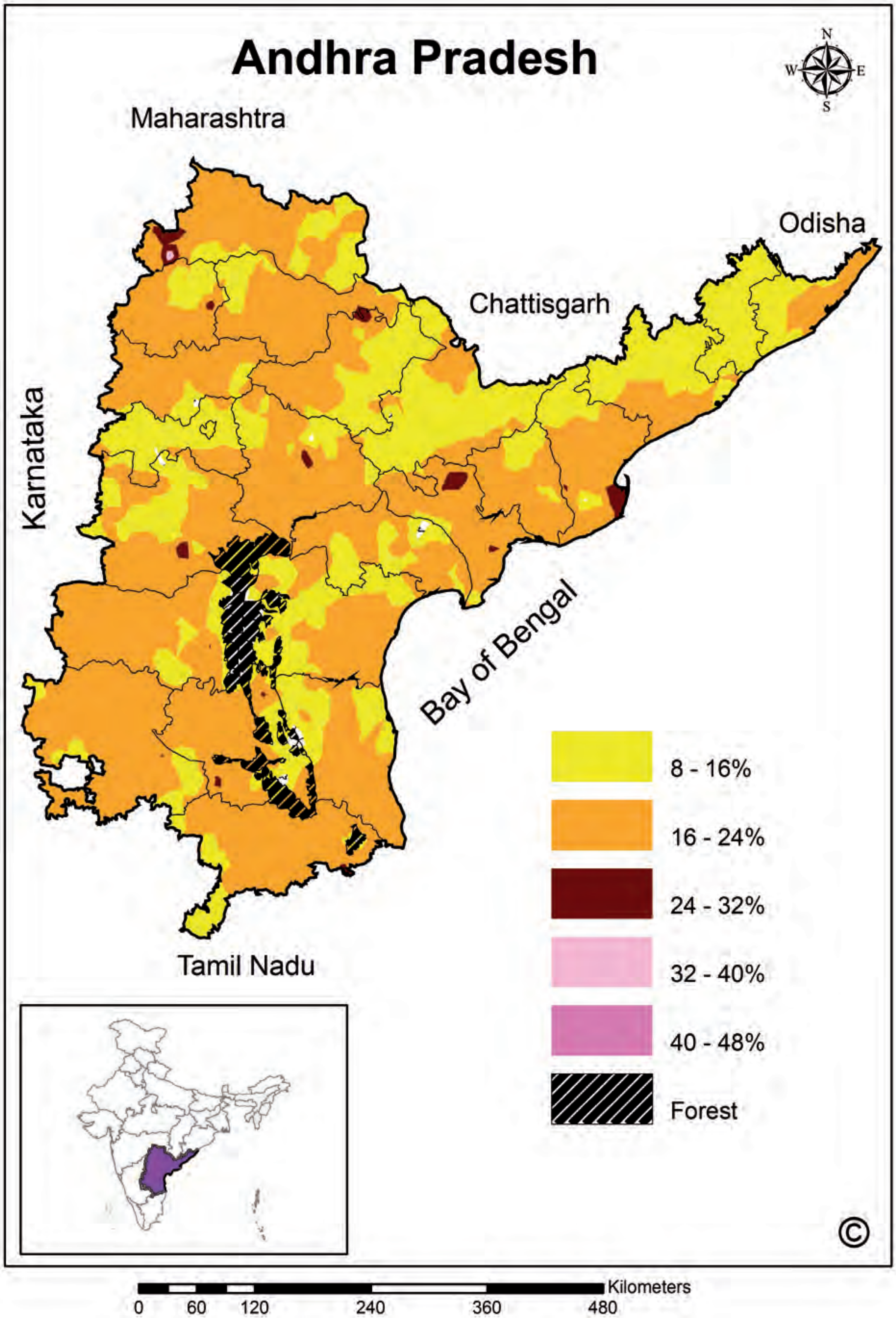


Fig. 82: Probability of occurrence of moderate drought in Andhra Pradesh

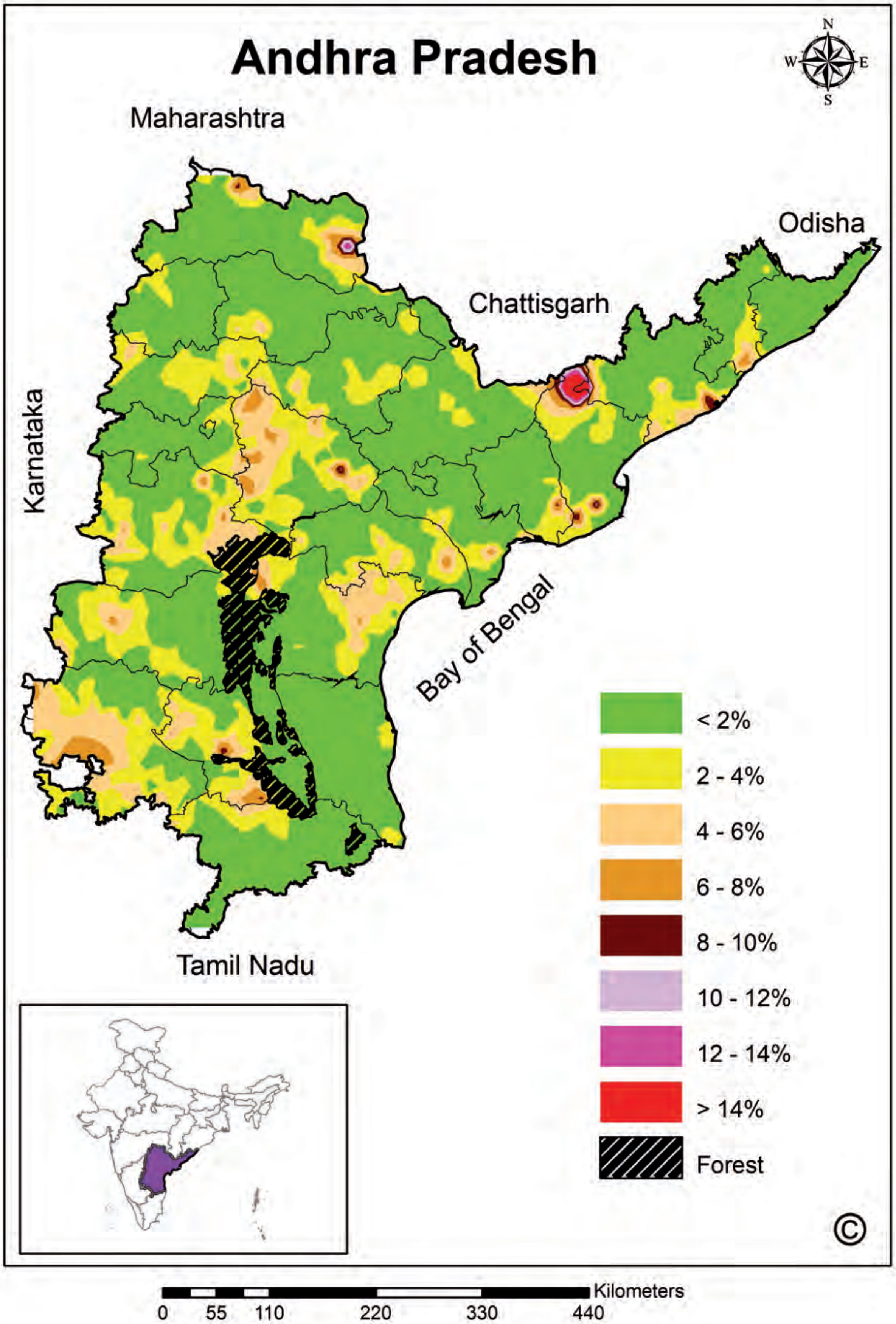


Fig. 83: Probability for the occurrence of severe drought in Andhra Pradesh

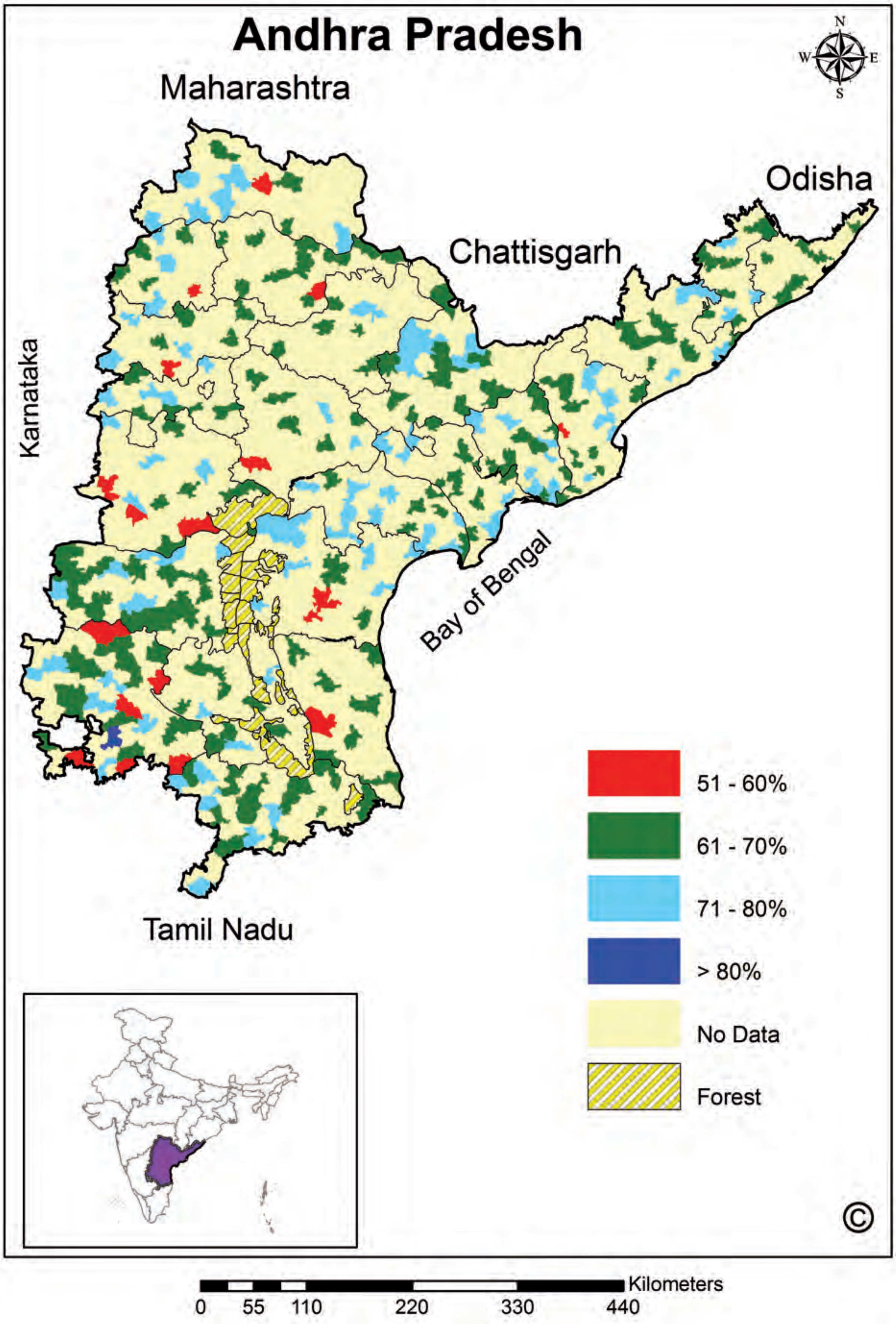


Fig. 84a: Probability of experiencing near normal conditions based on annual basis (SPI between -0.99 to +0.99)

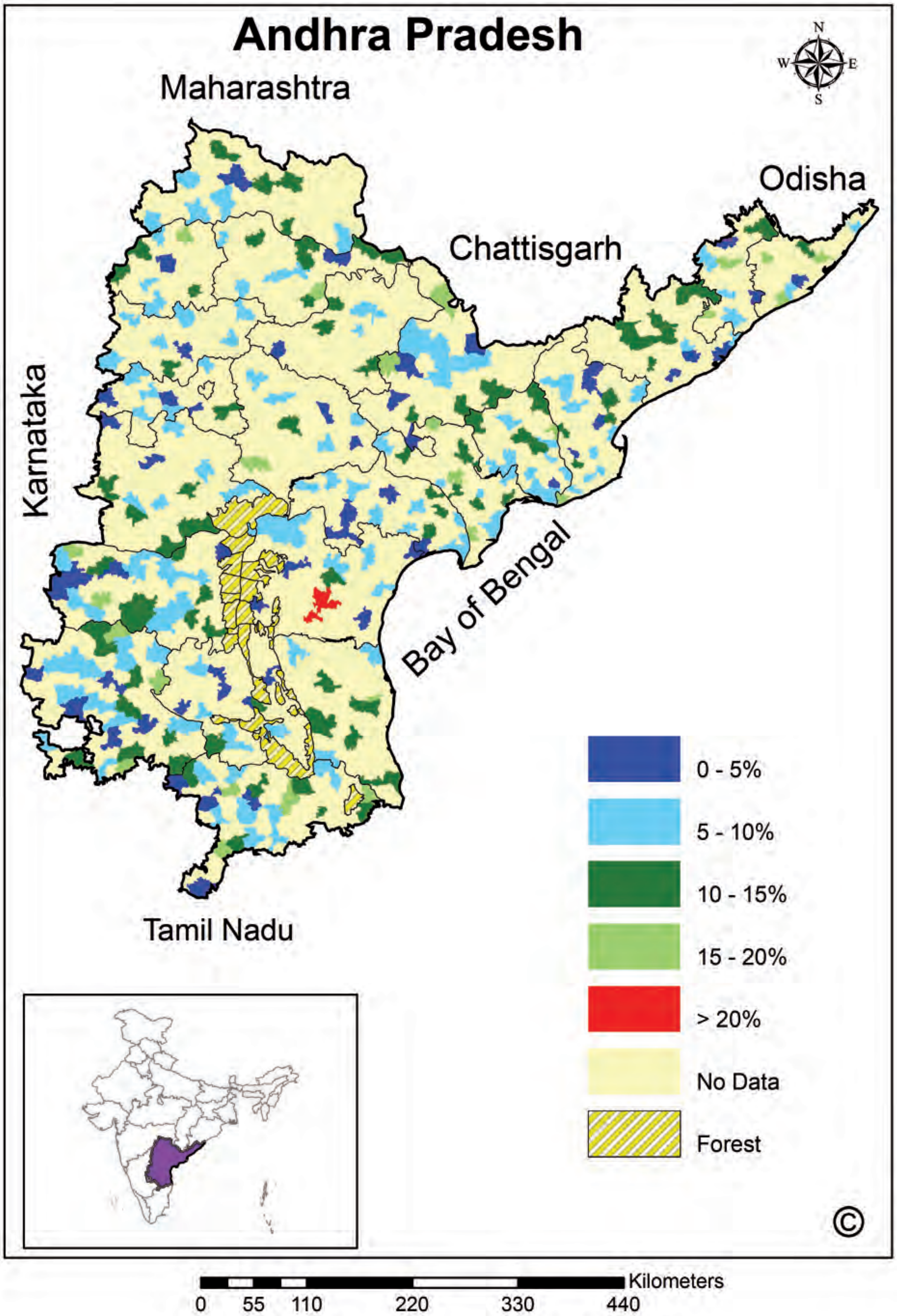


Fig. 84b: Probability of experiencing moderately dry conditions based on annual basis (SPI between -1.00 to -1.49)

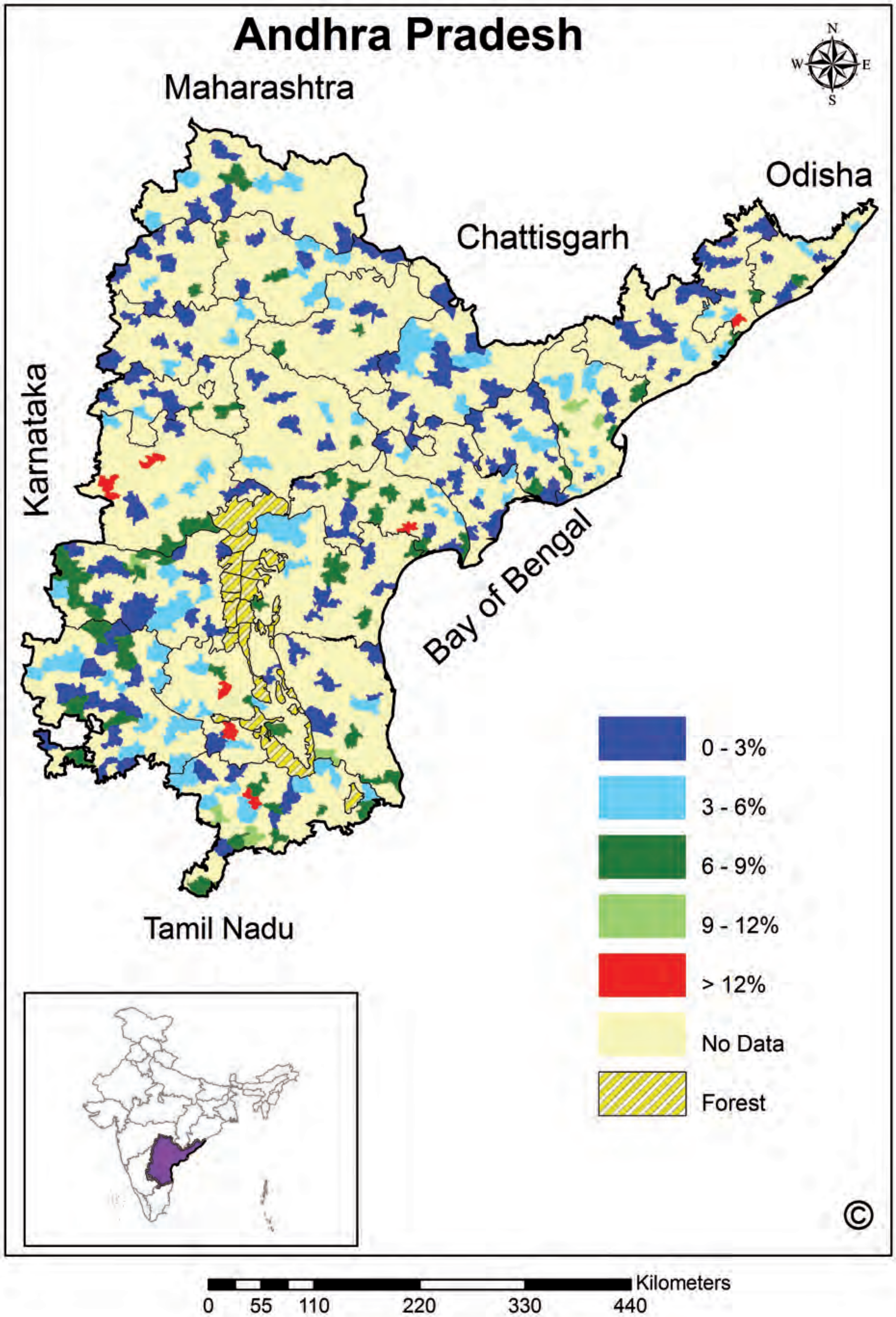


Fig. 84c: Probability of experiencing severely dry conditions based on annual basis (SPI between -1.5 to -1.99)

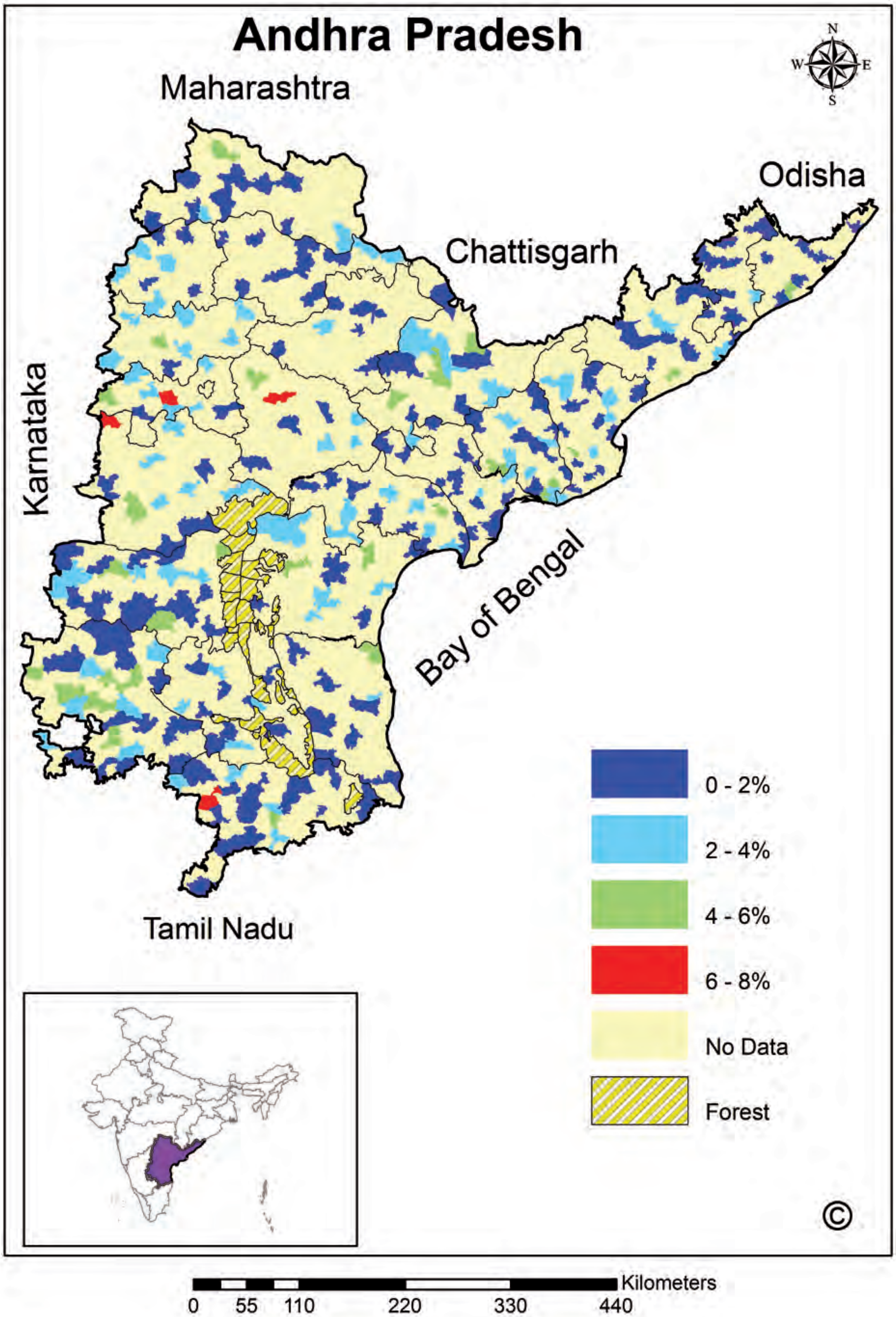


Fig. 84d: Probability of experiencing extremely dry conditions based on annual basis (SPI less than -2.0)

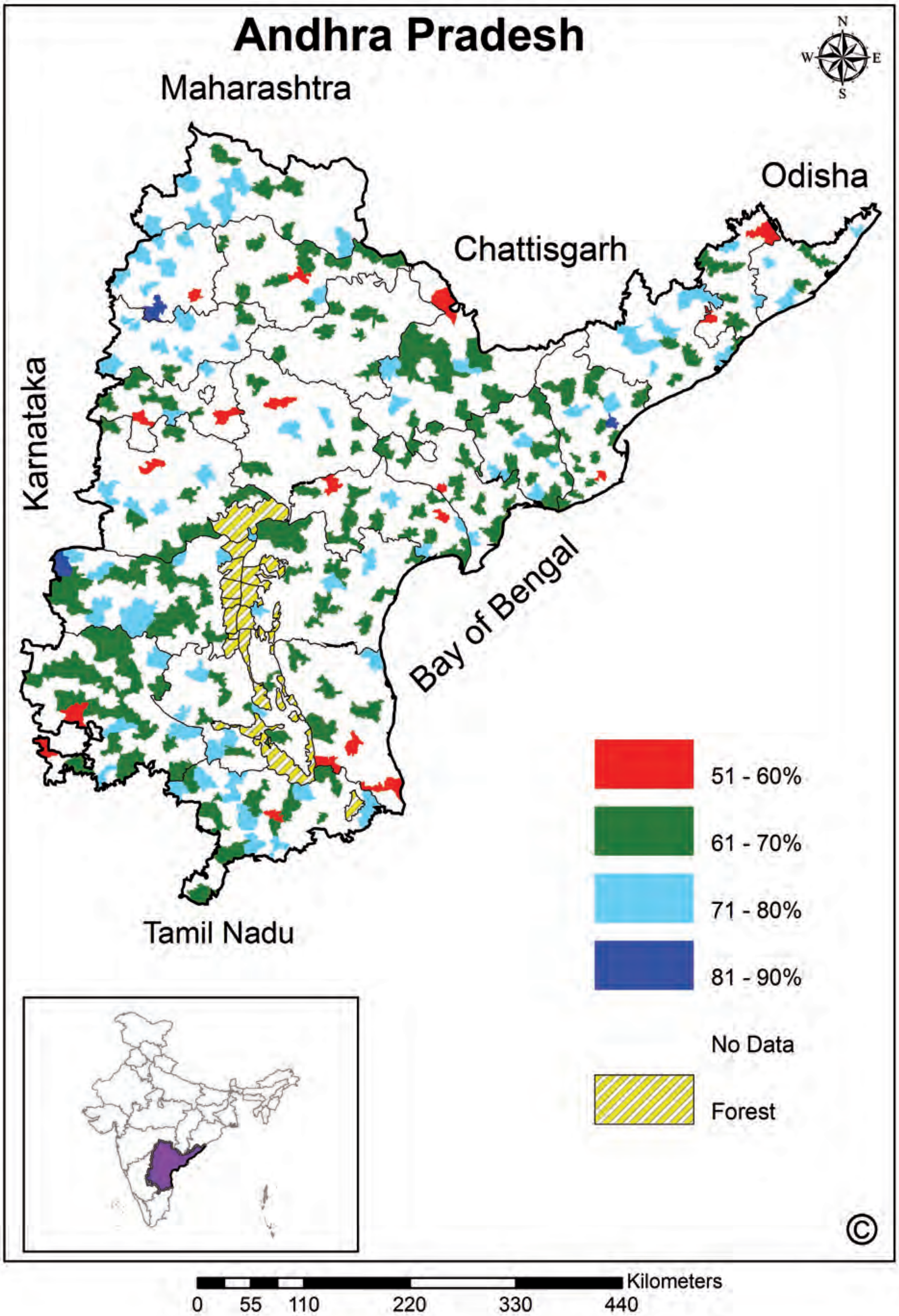


Fig. 85a: Probability of near normal rainfall during Southwest monsoon (SPI between -0.99 to +0.99) in Andhra Pradesh

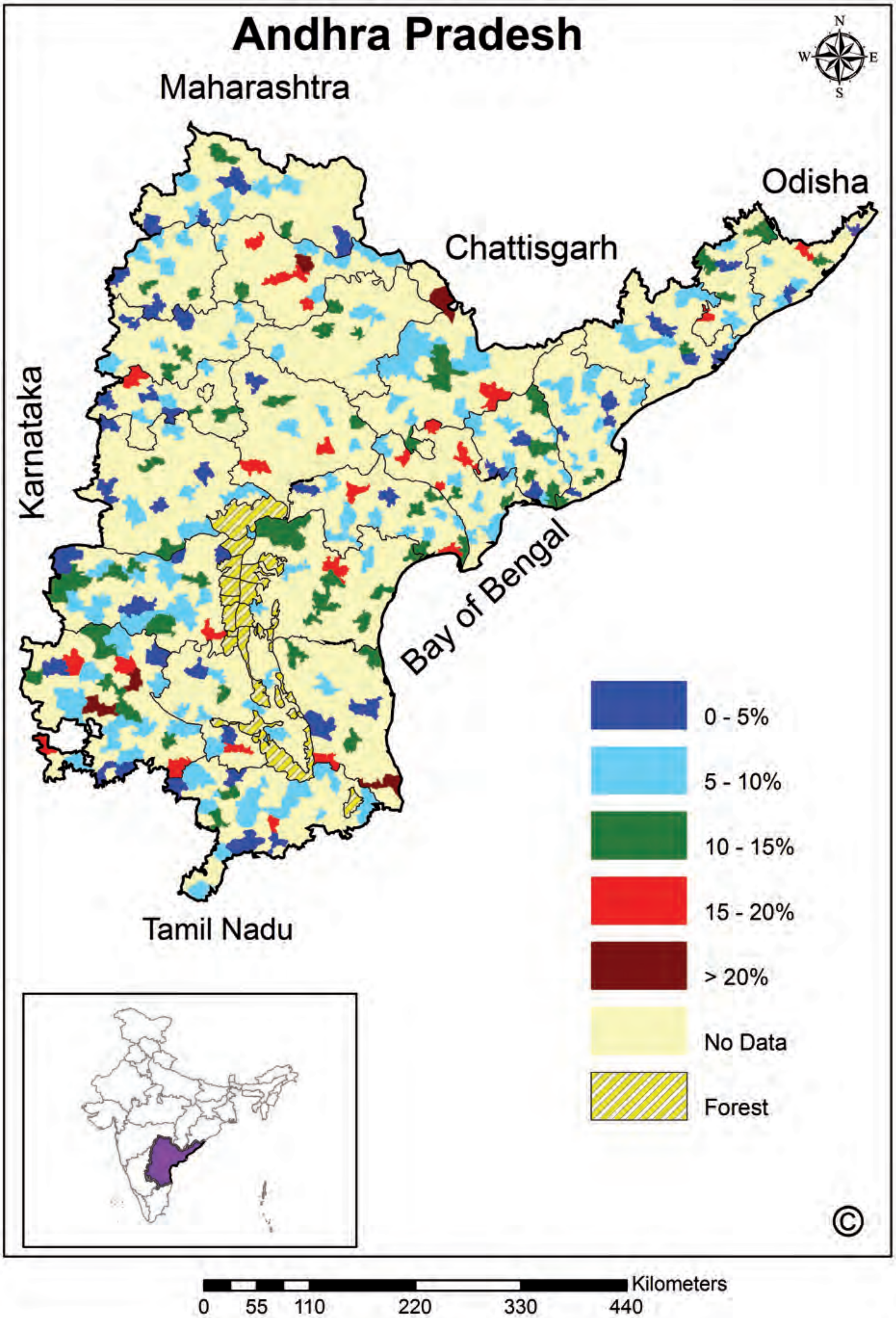


Fig. 85b: Probability of moderately dry rainfall during Southwest monsoon (SPI between -1.00 to -1.49) in Andhra Pradesh

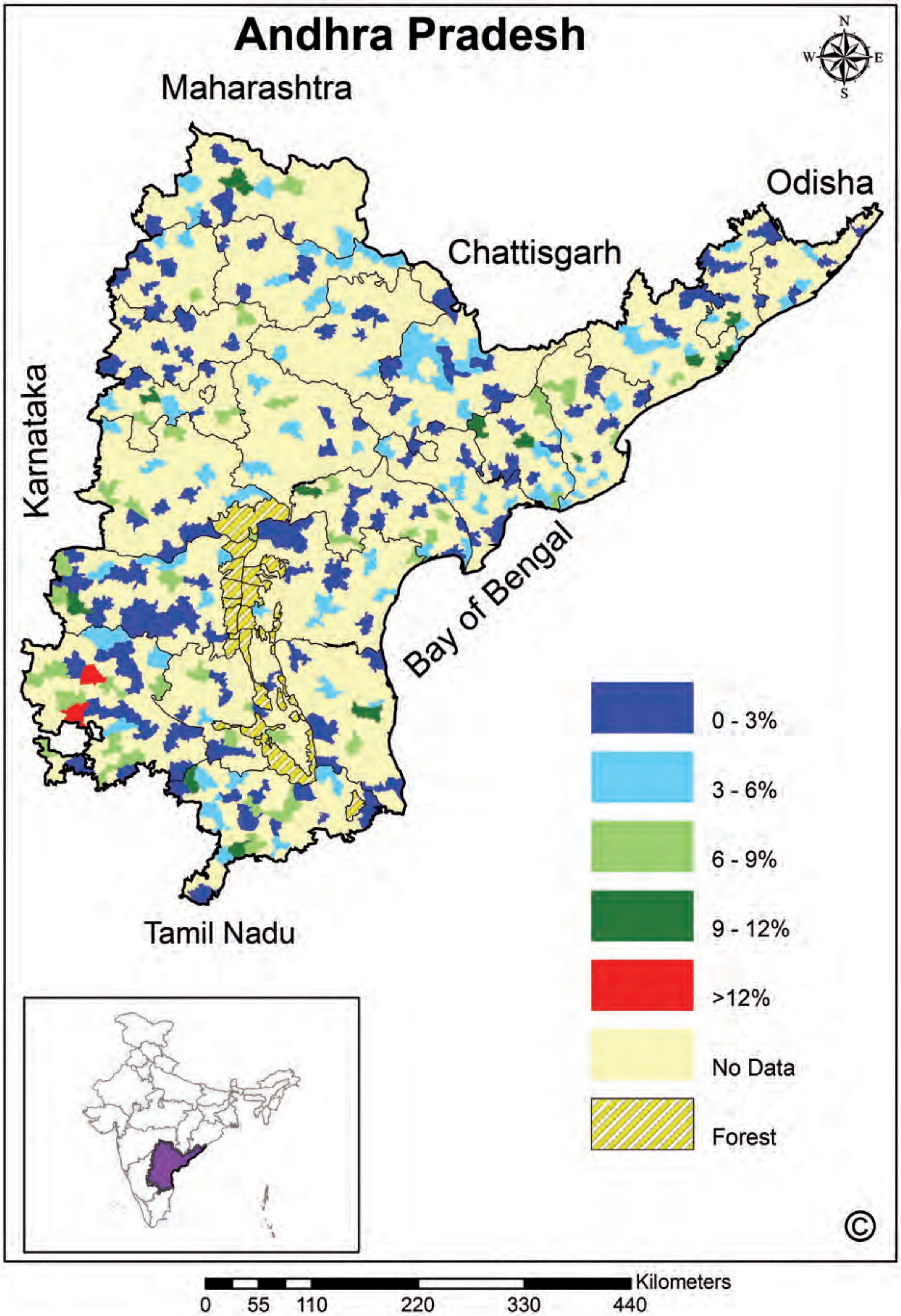


Fig. 85c: Probability of severely dry rainfall during Southwest monsoon (SPI between -1.5 to -1.99) in Andhra Pradesh

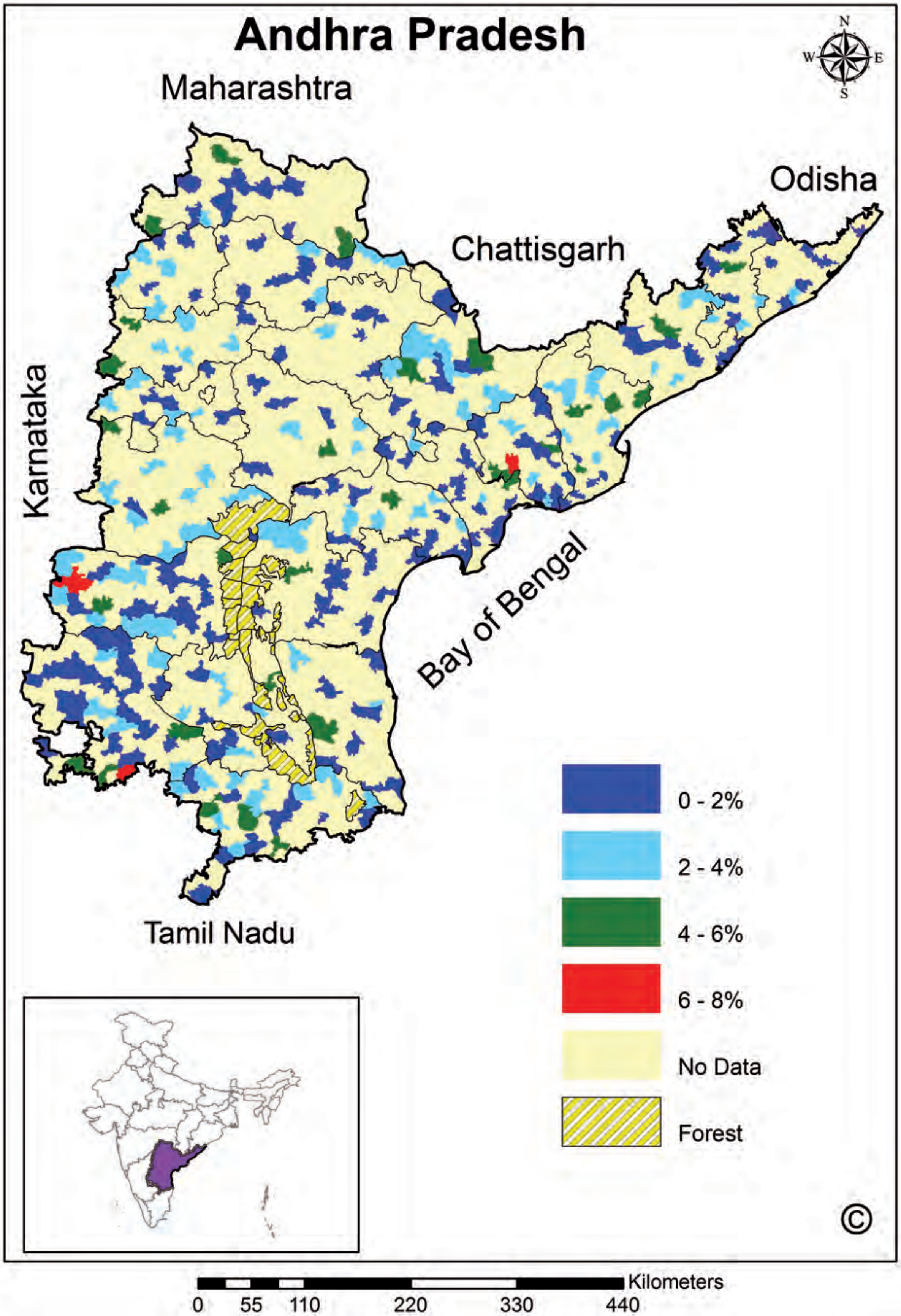


Fig. 85d: Probability of extremely dry rainfall during Southwest monsoon (SPI less than -2.0) in Andhra Pradesh

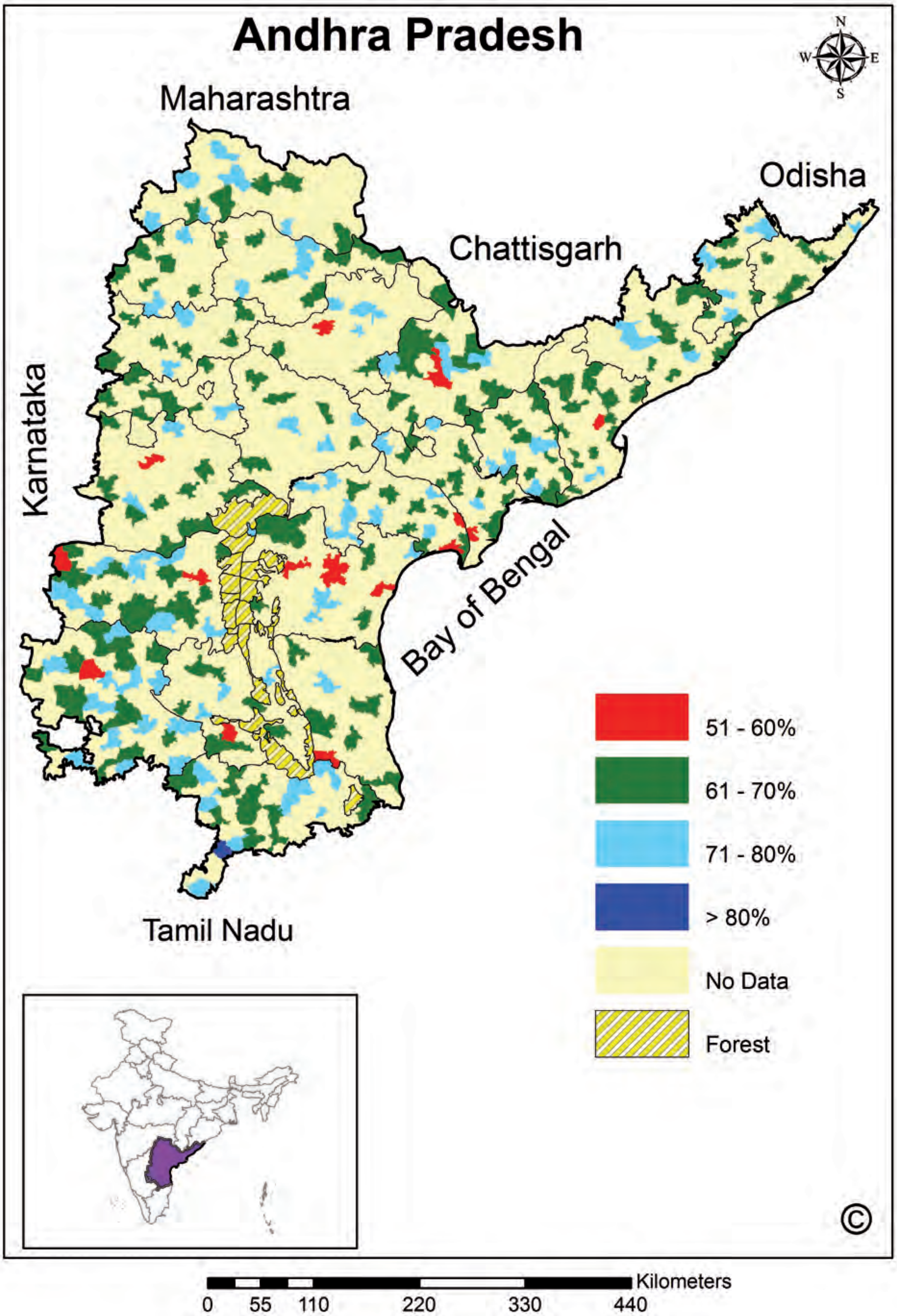


Fig. 86a: Probability of near normal rainfall during Northeast monsoon (SPI between -0.99 to +0.99) in Andhra Pradesh

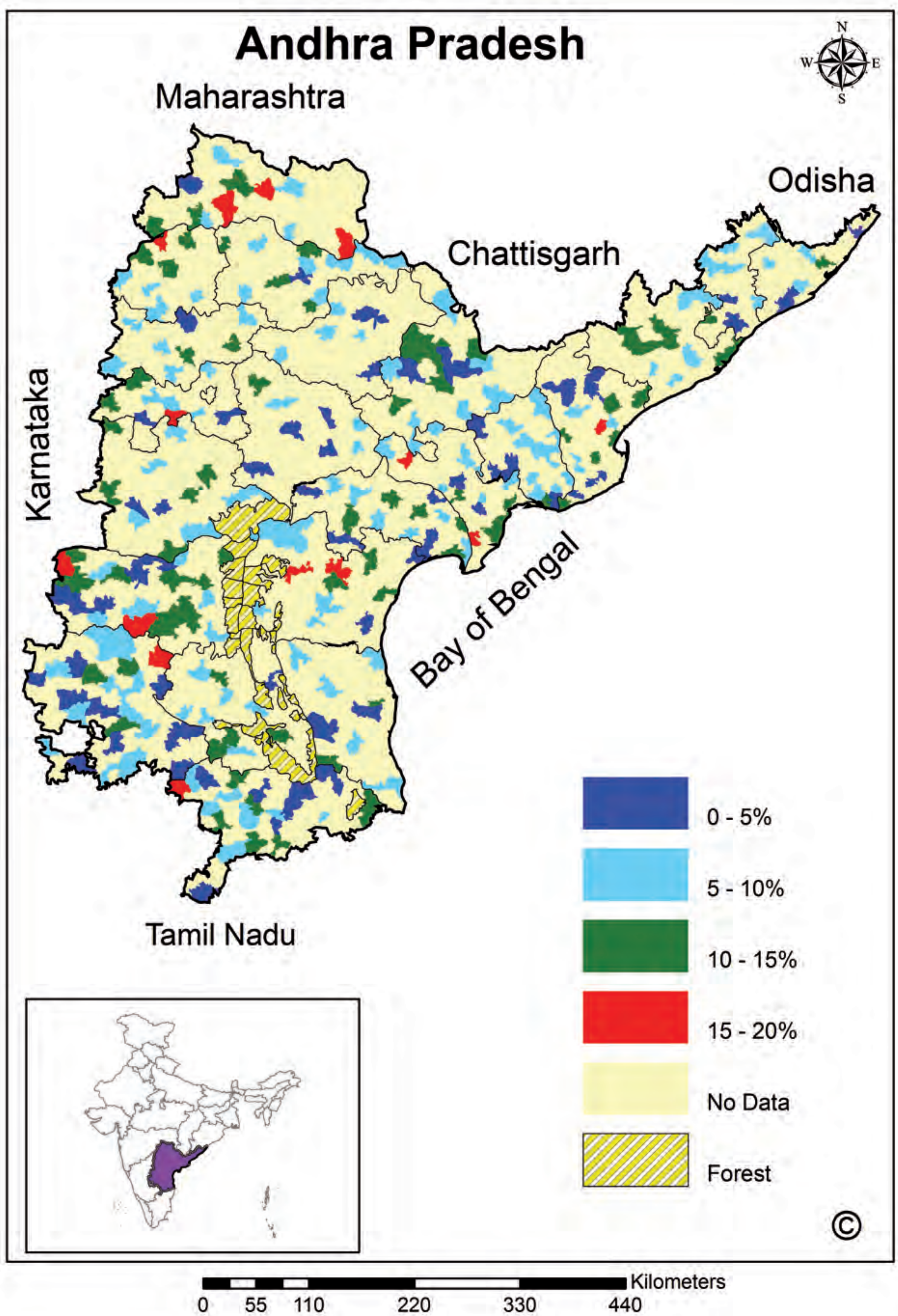


Fig. 86b: Probability of moderately dry rainfall during Northeast monsoon (SPI between -1.00 to -1.49) in Andhra Pradesh

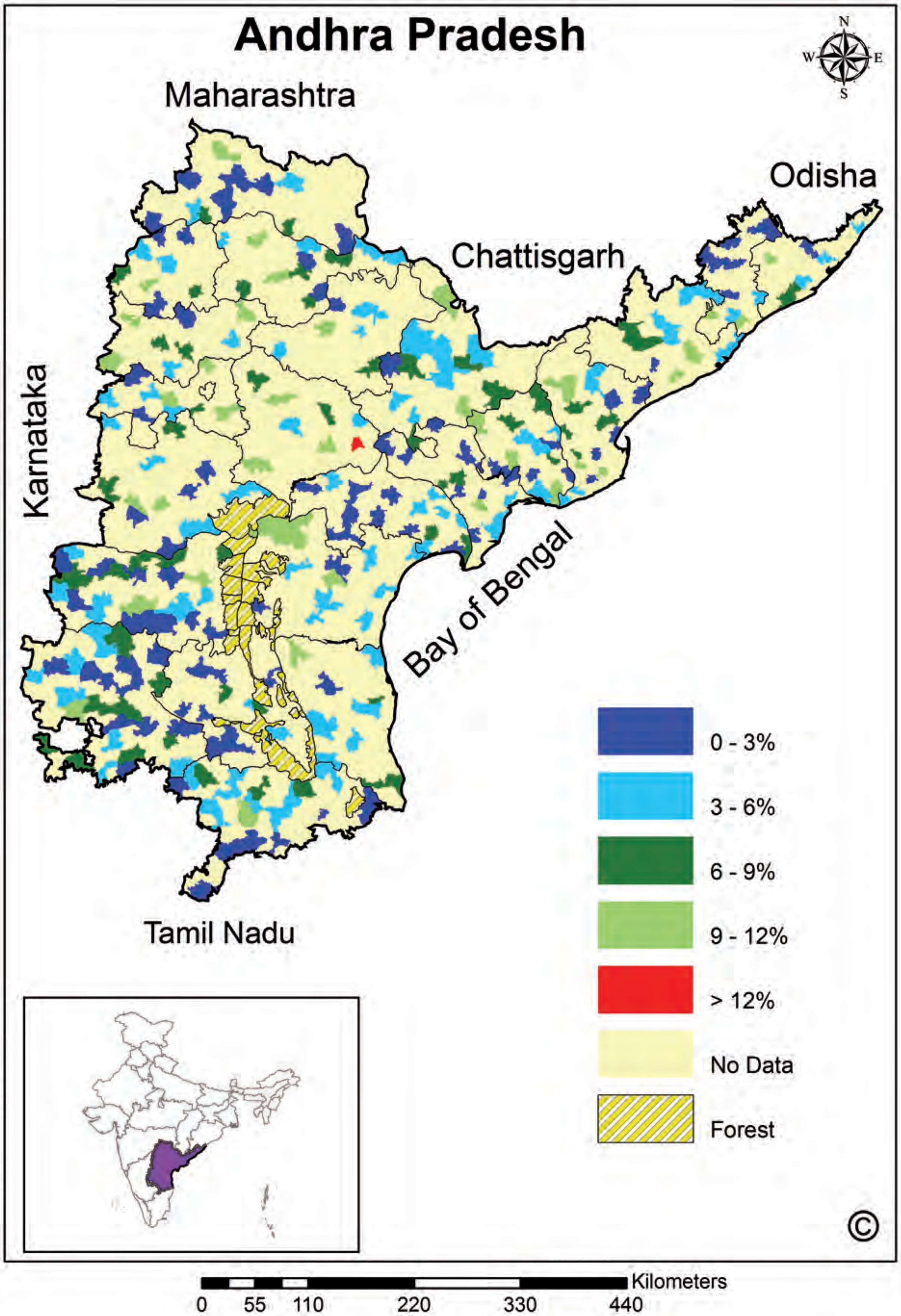


Fig. 86c: Probability of severely dry rainfall during Northeast monsoon (SPI between -1.5 to -1.99) in Andhra Pradesh

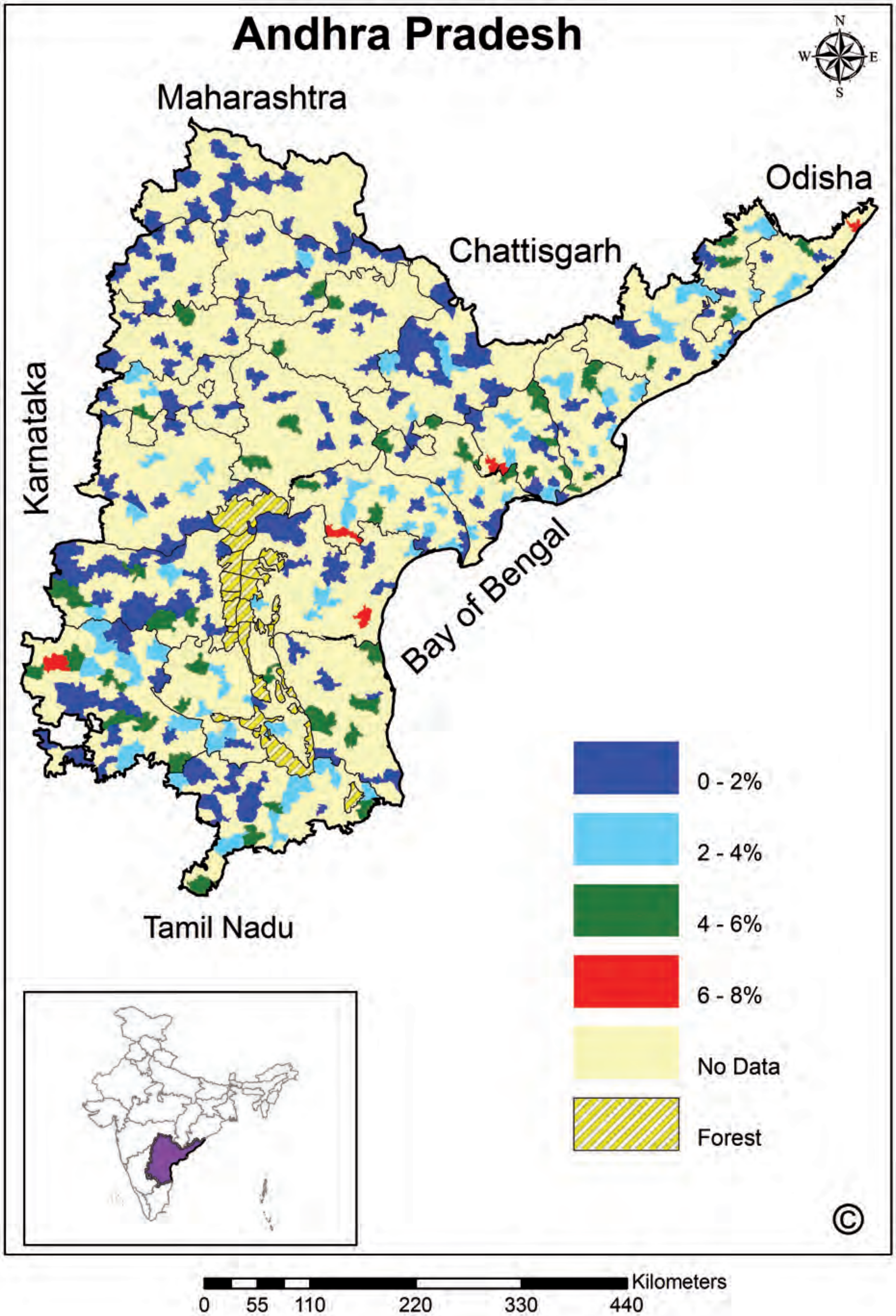


Fig. 86d: Probability of extremely dry rainfall during Northeast monsoon (SPI less than -2.0) in Andhra Pradesh

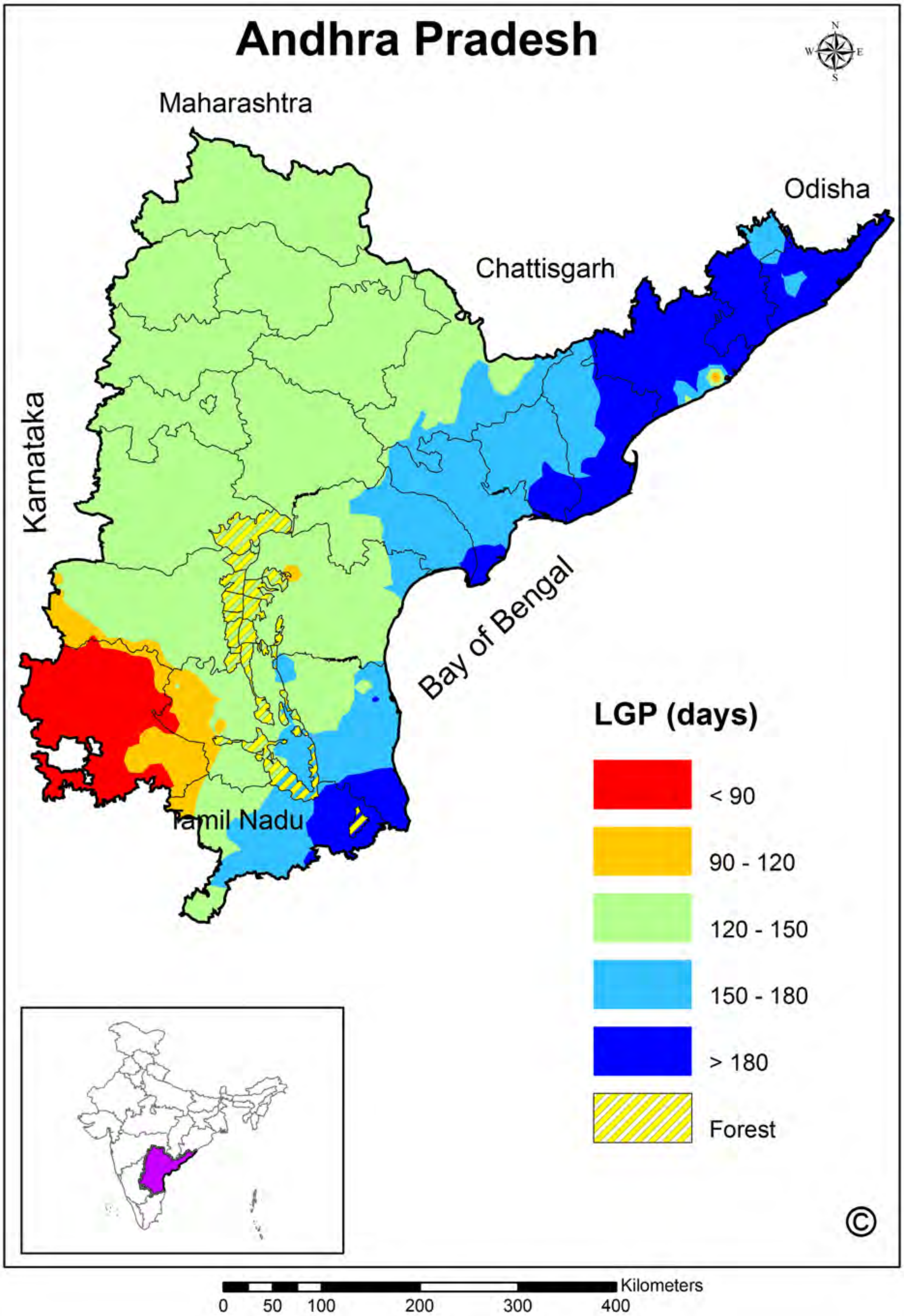


Fig. 87: Length of growing period (LGP) in Andhra Pradesh

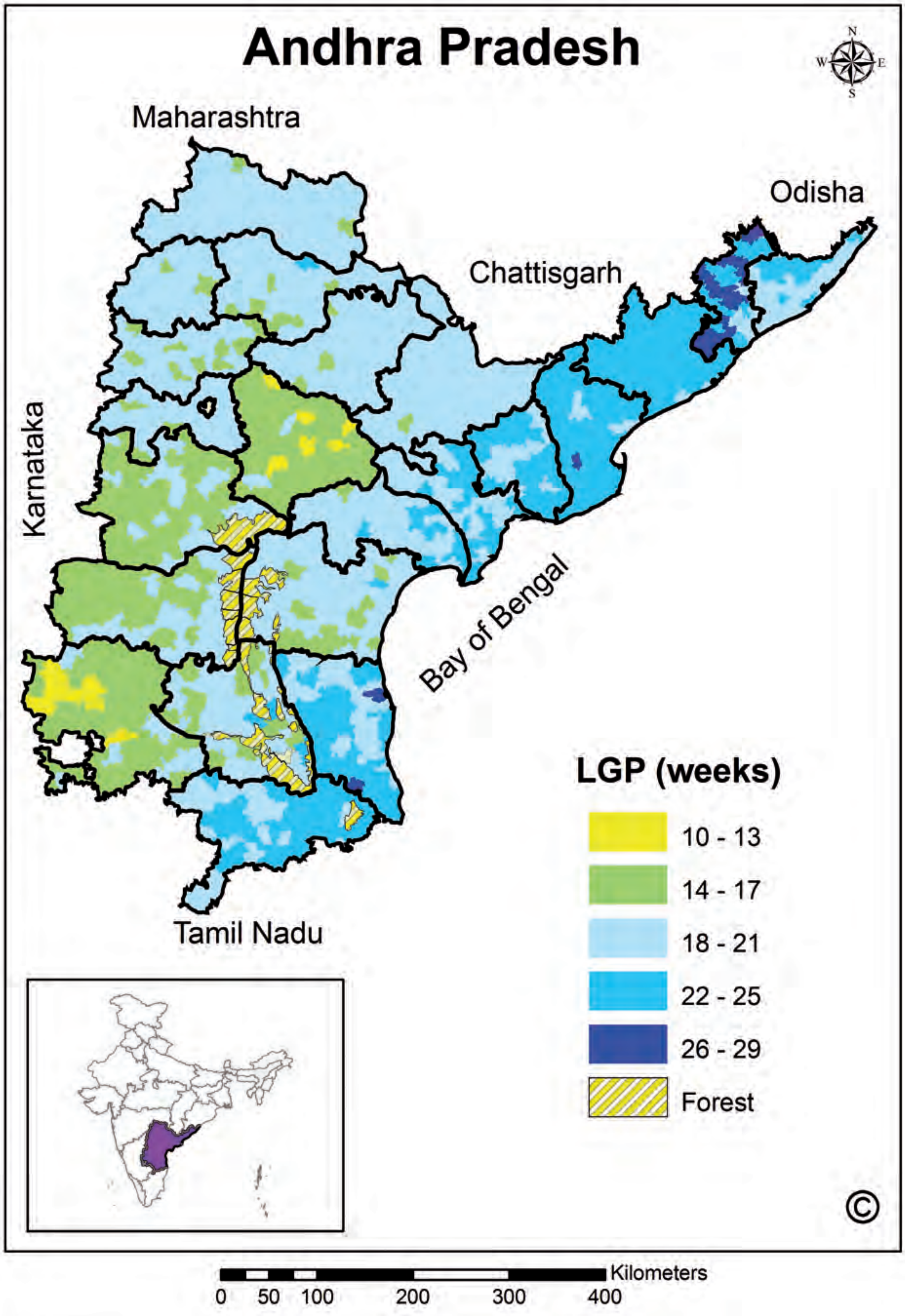


Fig. 88a: LGP (weeks) soils having water holding capacity of 50 mm in Andhra Pradesh

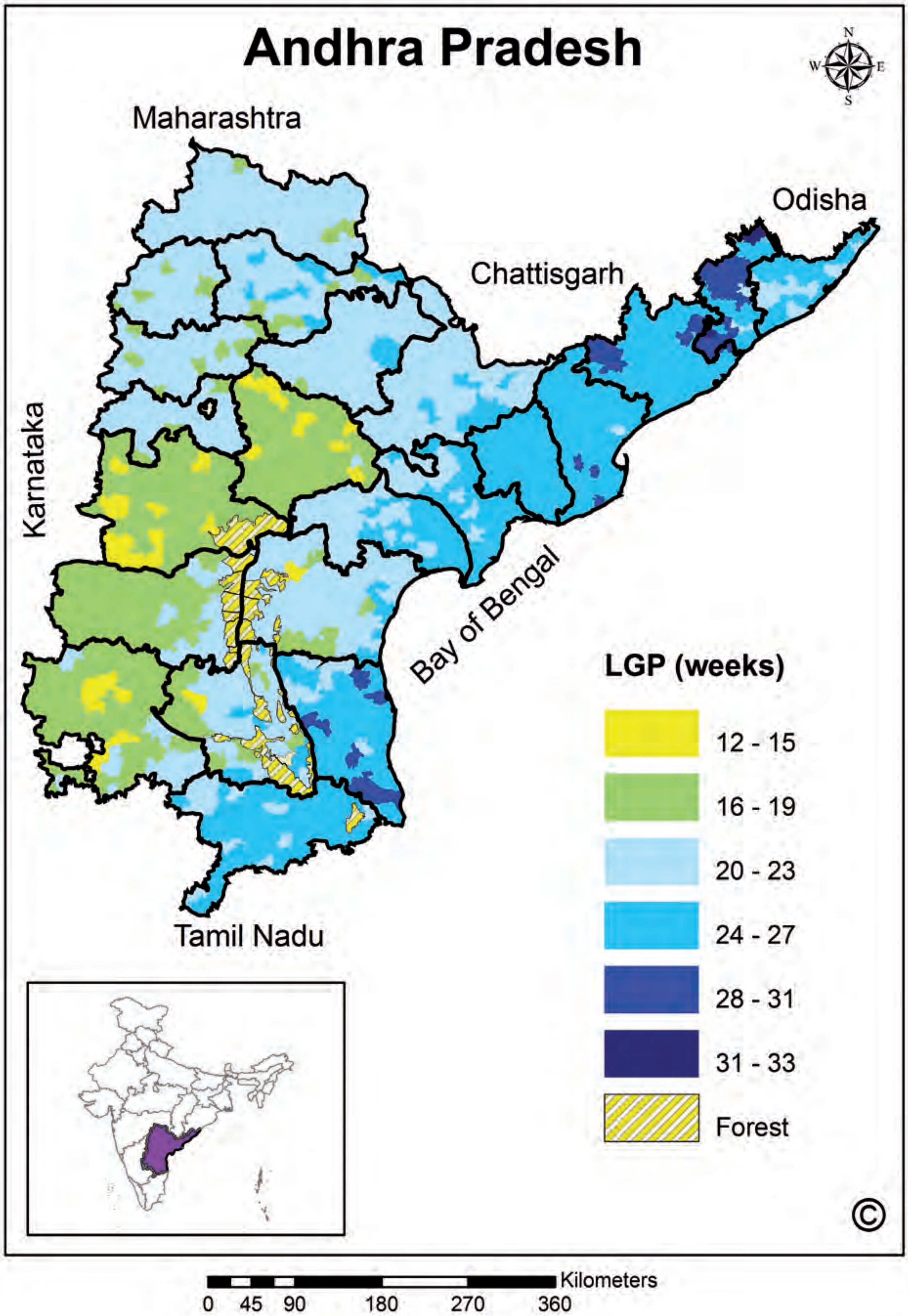


Fig. 88b: LGP (weeks) soils having water holding capacity of 100 mm in Andhra Pradesh

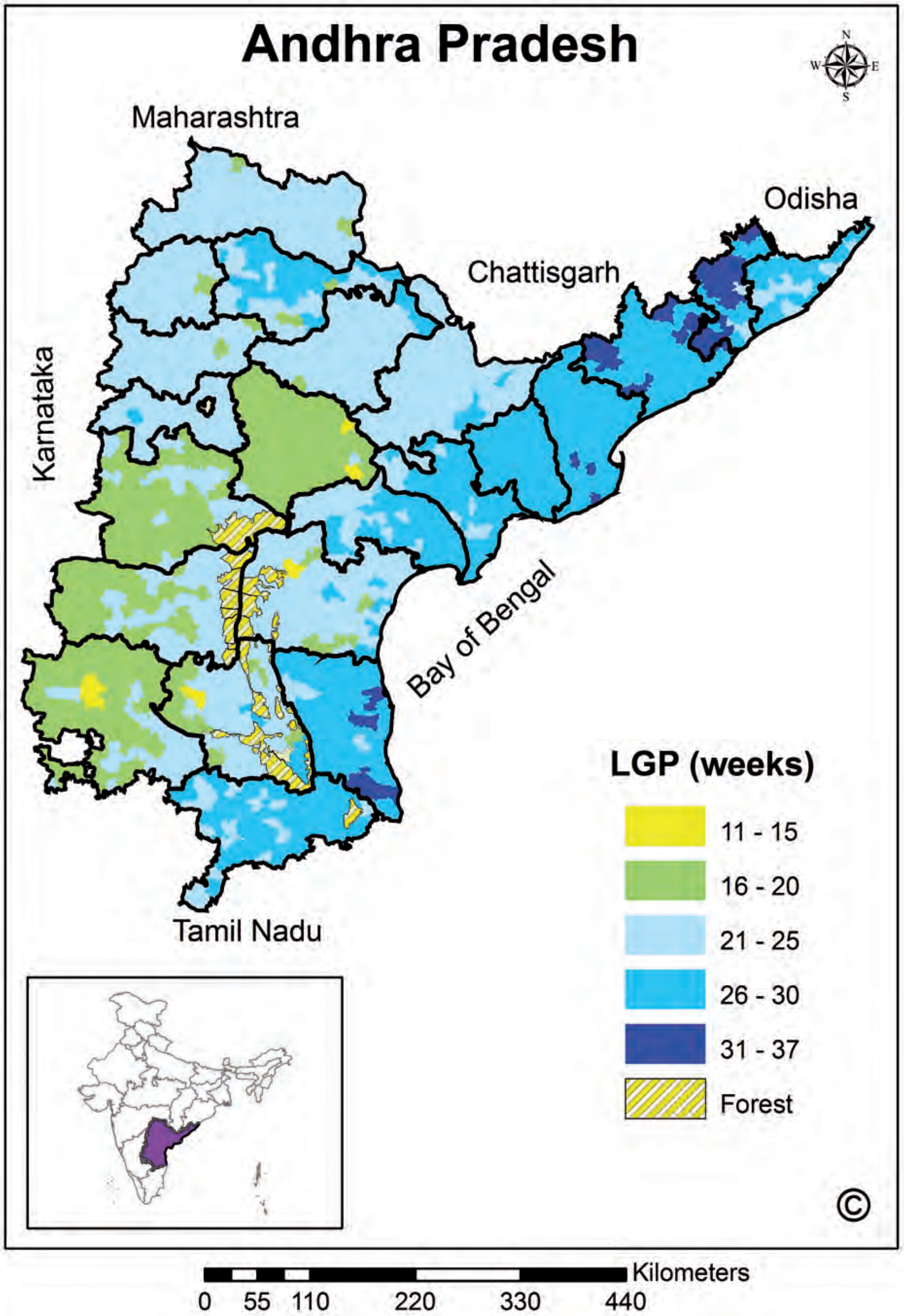


Fig. 88c: LGP (weeks) soils having water holding capacity of 150 mm in Andhra Pradesh

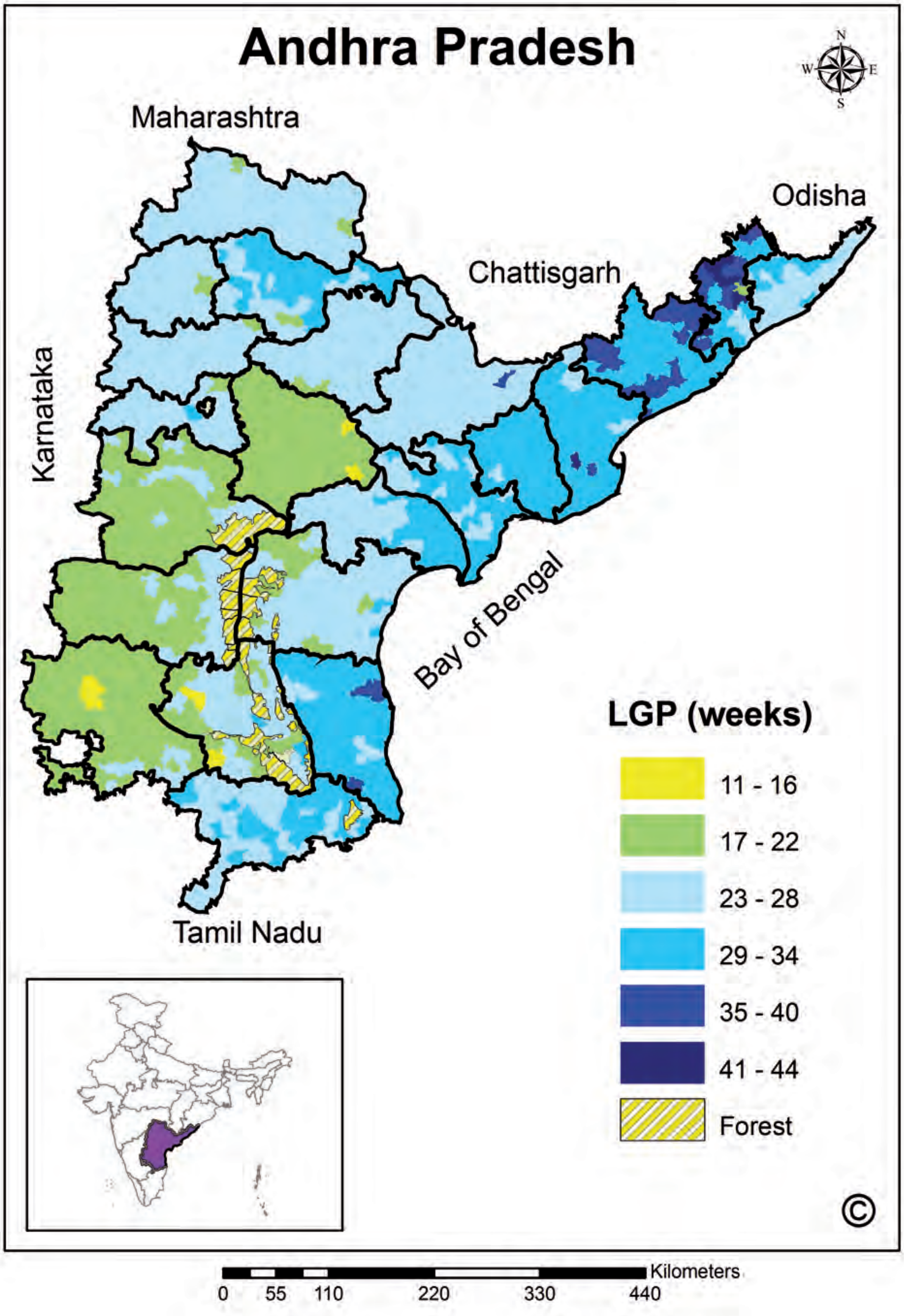


Fig. 88d: LGP (weeks) soils having water holding capacity of 200 mm in Andhra Pradesh

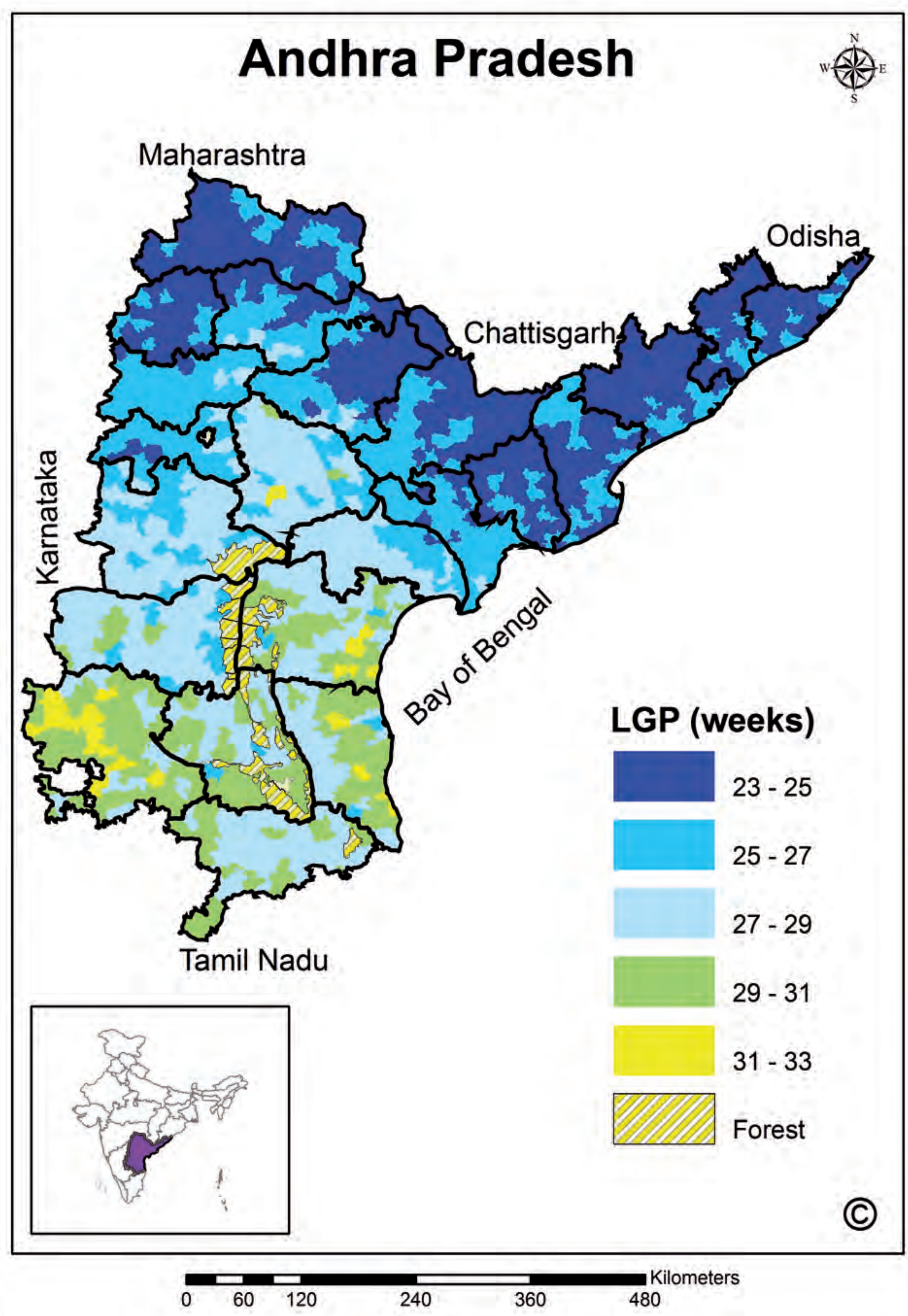


Fig. 89a: Commencement of growing season (SMW) for soils having water holding capacity of 50 mm in Andhra Pradesh

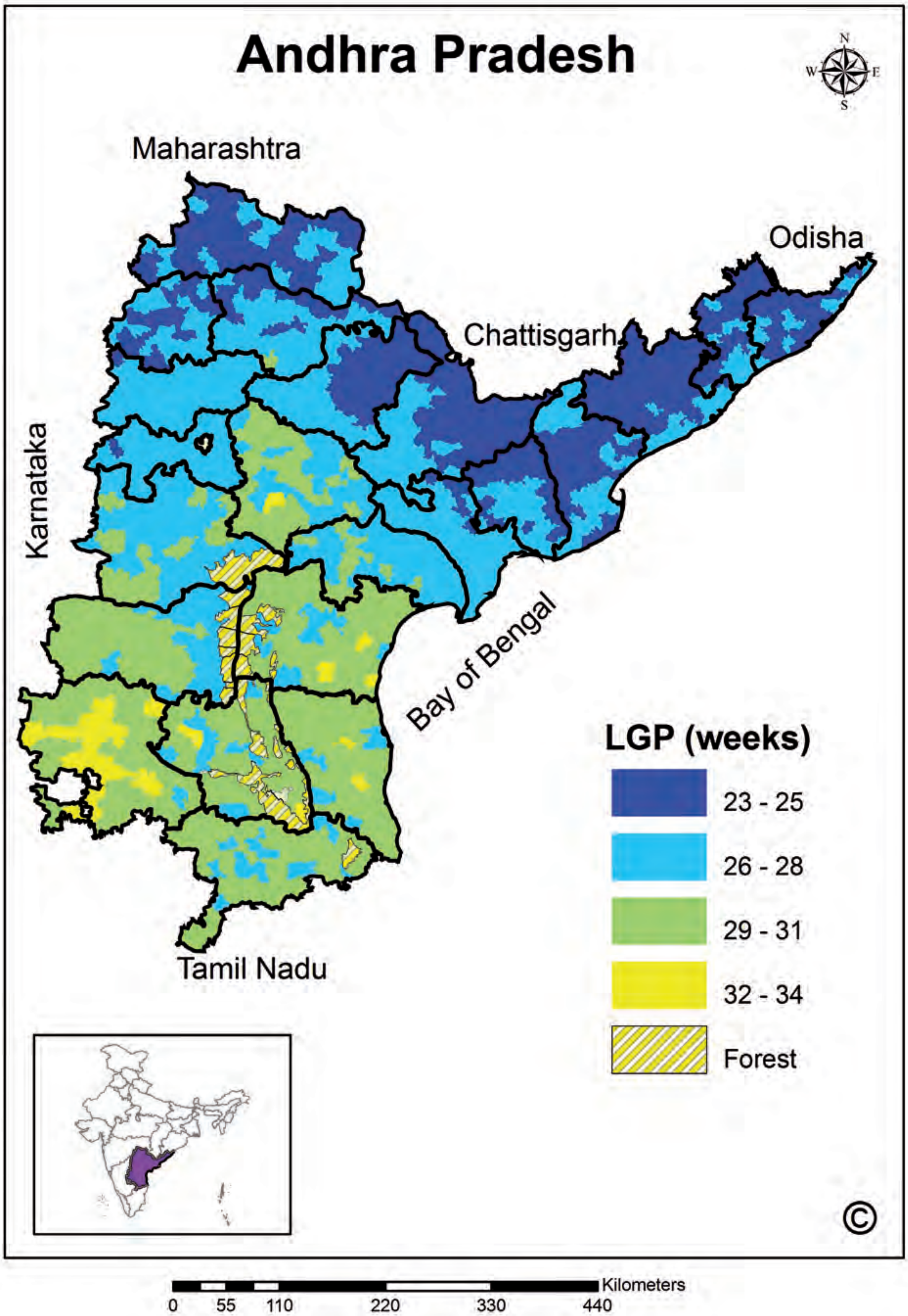


Fig. 89b: Commencement of growing season (SMW) for soils having water holding capacity of 100 mm in Andhra Pradesh

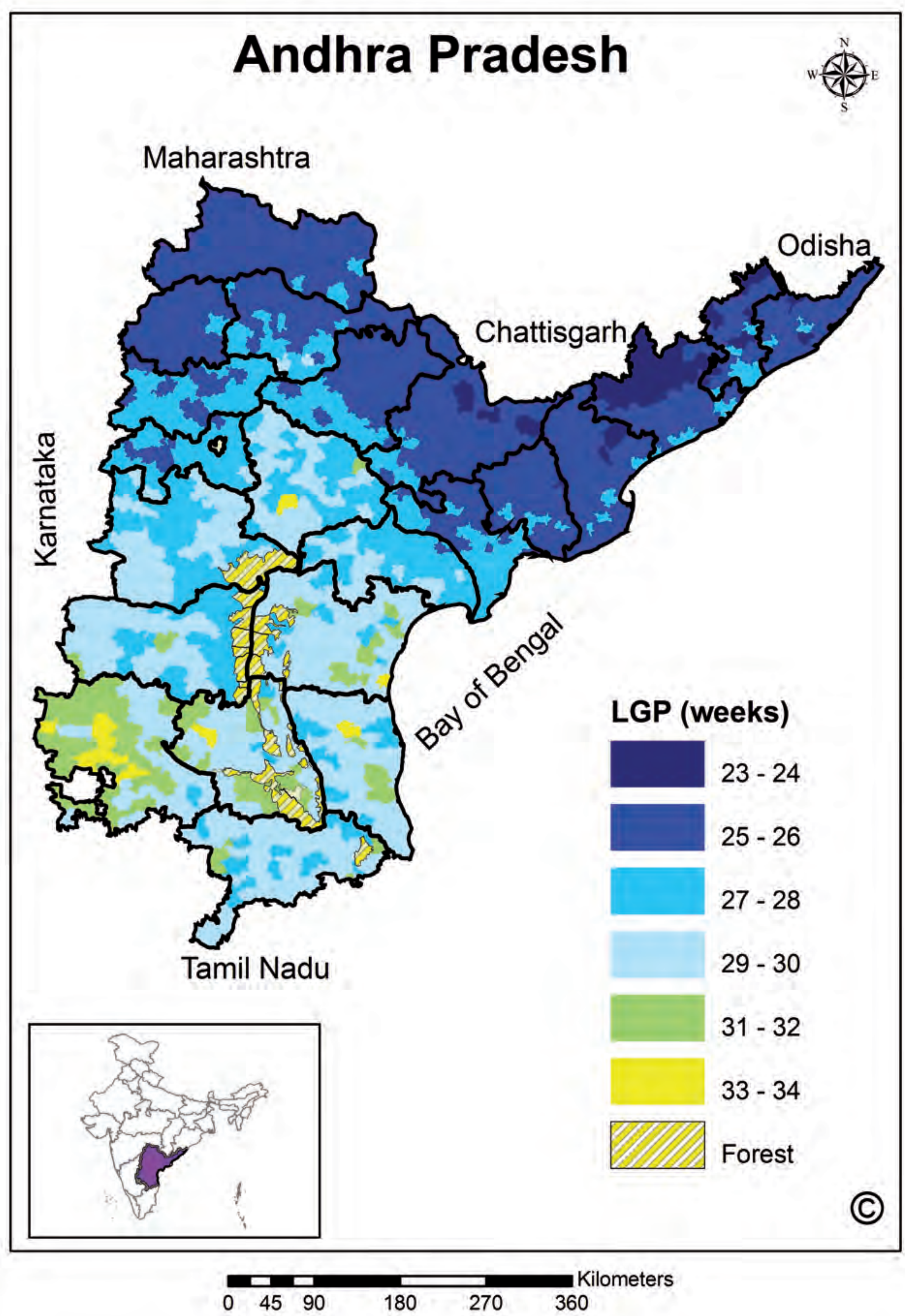


Fig. 89c: Commencement of growing season (SMW) for soils having water holding capacity of 150 mm in Andhra Pradesh

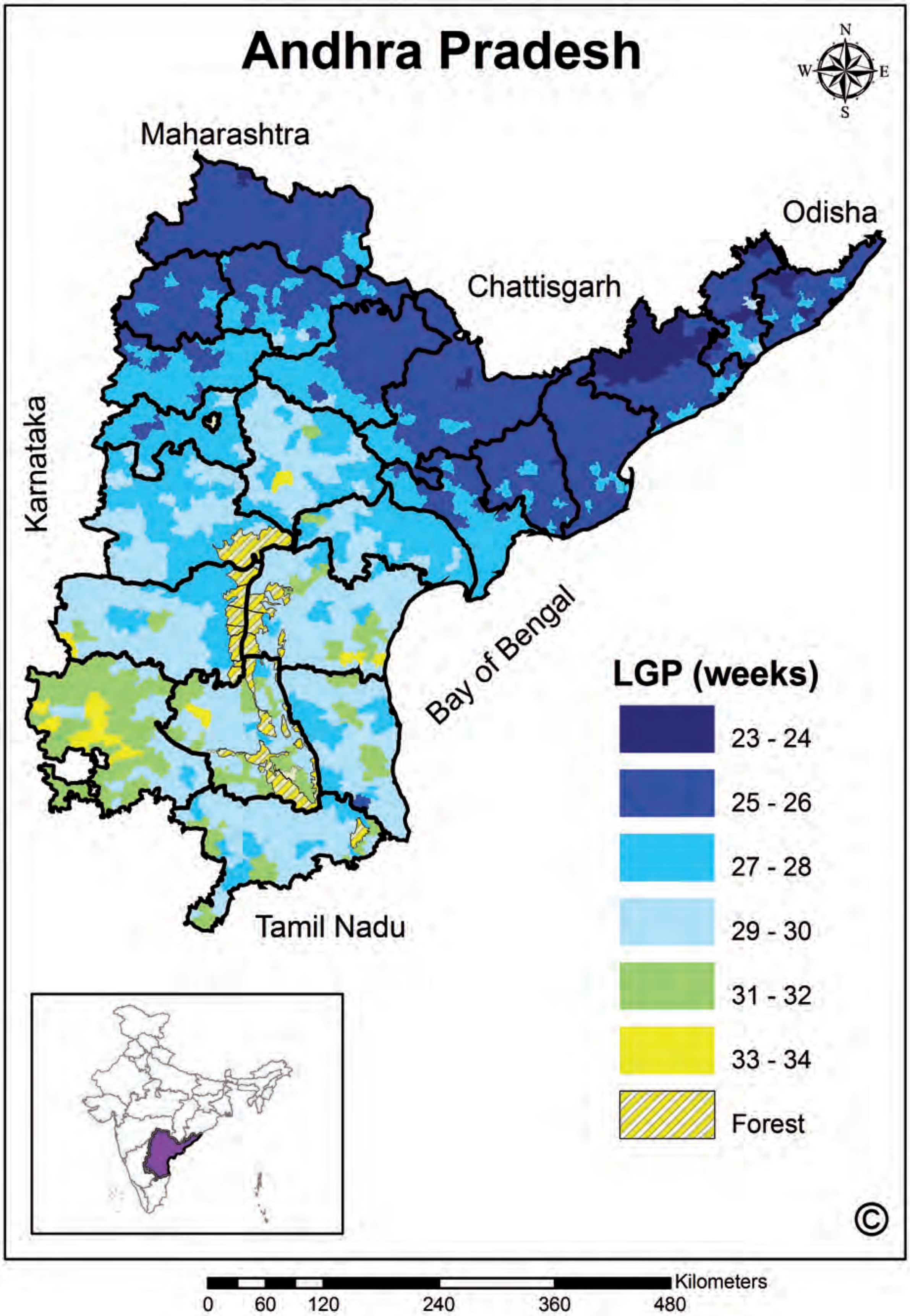


Fig. 89d: Commencement of growing season (SMW) for soils having water holding capacity of 200 mm in Andhra Pradesh

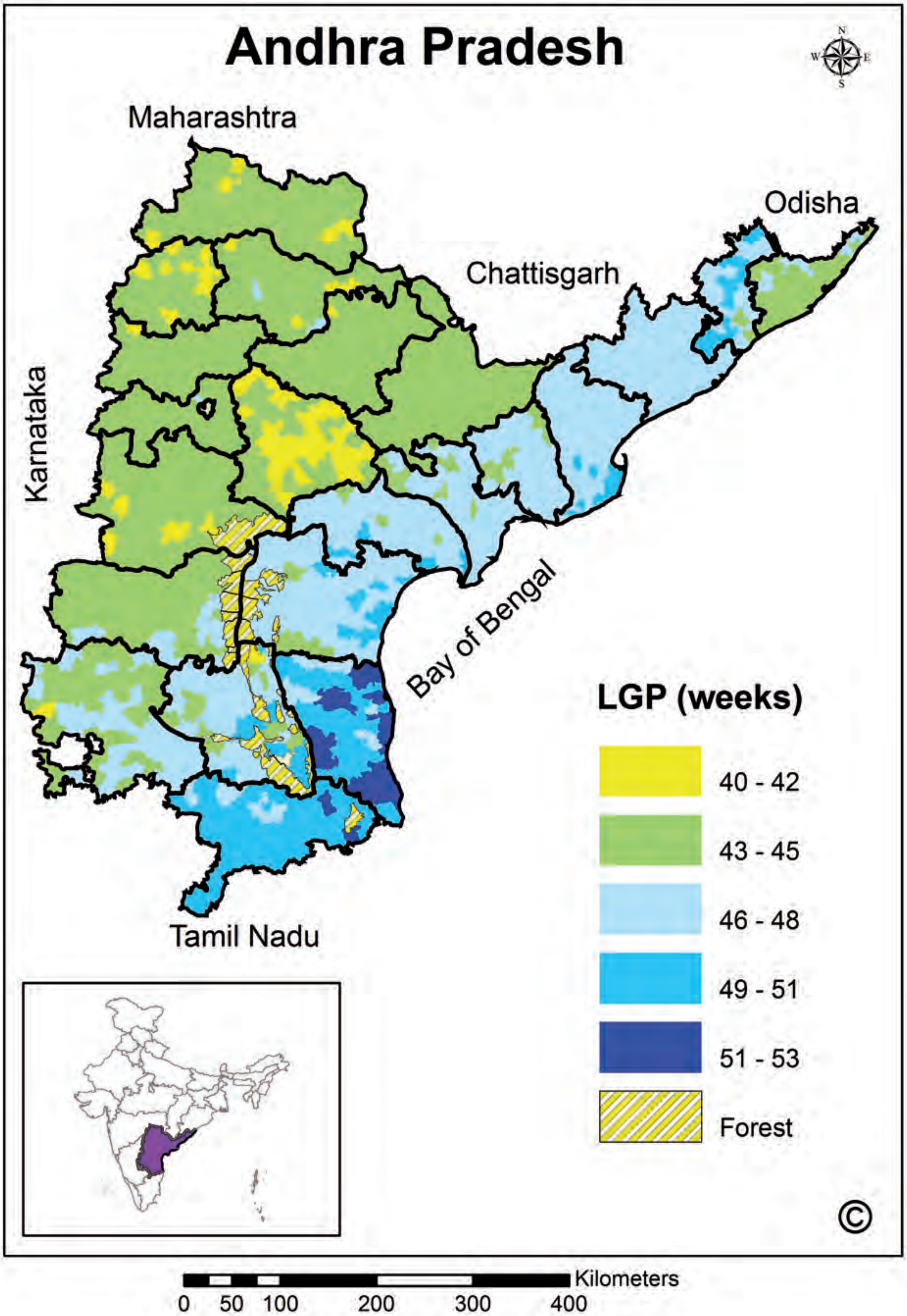


Fig. 90a: Termination of growing season (SMW) for soils having water holding capacity of 50 mm in Andhra Pradesh

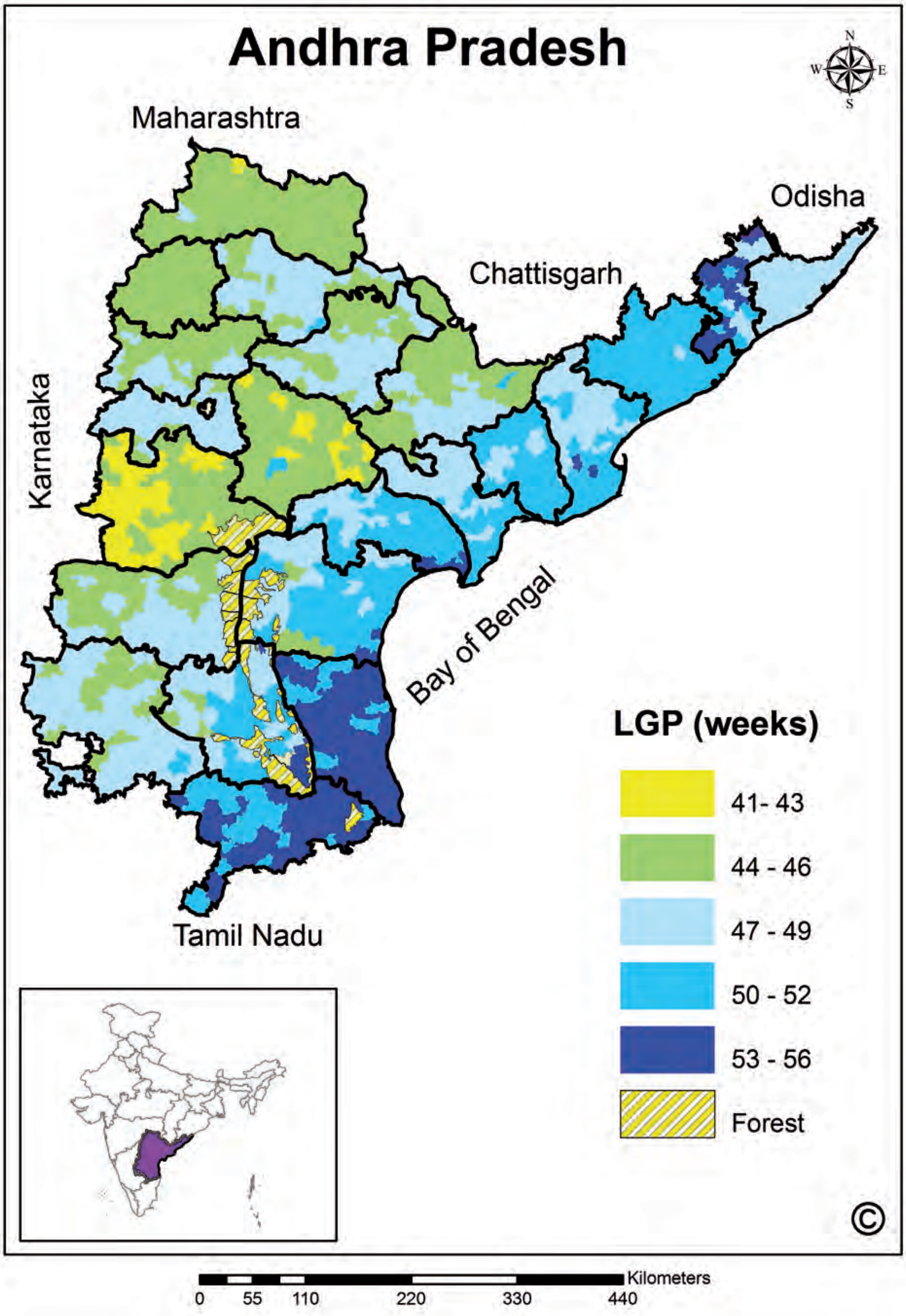


Fig. 90b: Termination of growing season (SMW) for soils having water holding capacity of 100 mm in Andhra Pradesh

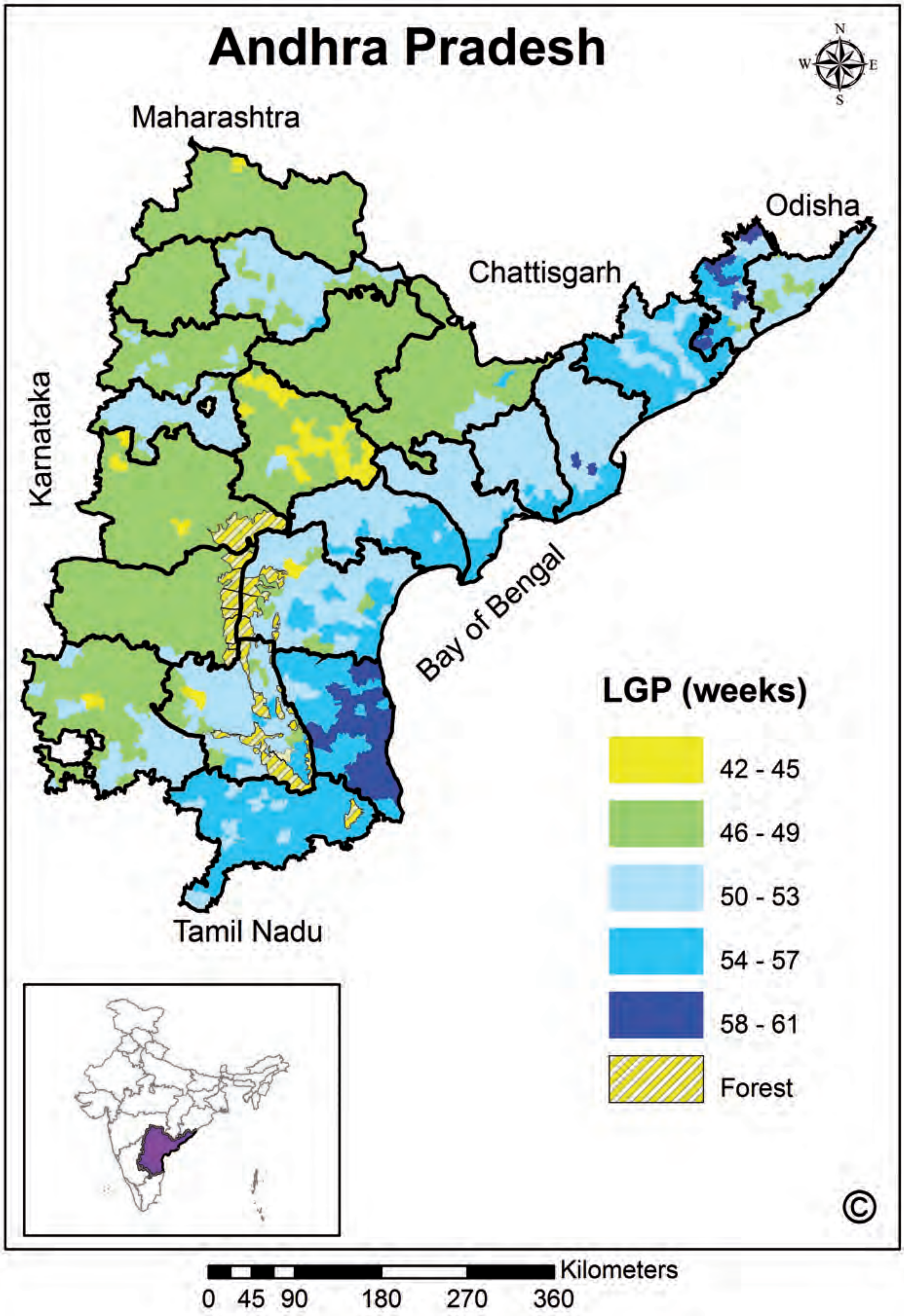


Fig. 90c: Termination of growing season (SMW) for soils having water holding capacity of 150 mm in Andhra Pradesh

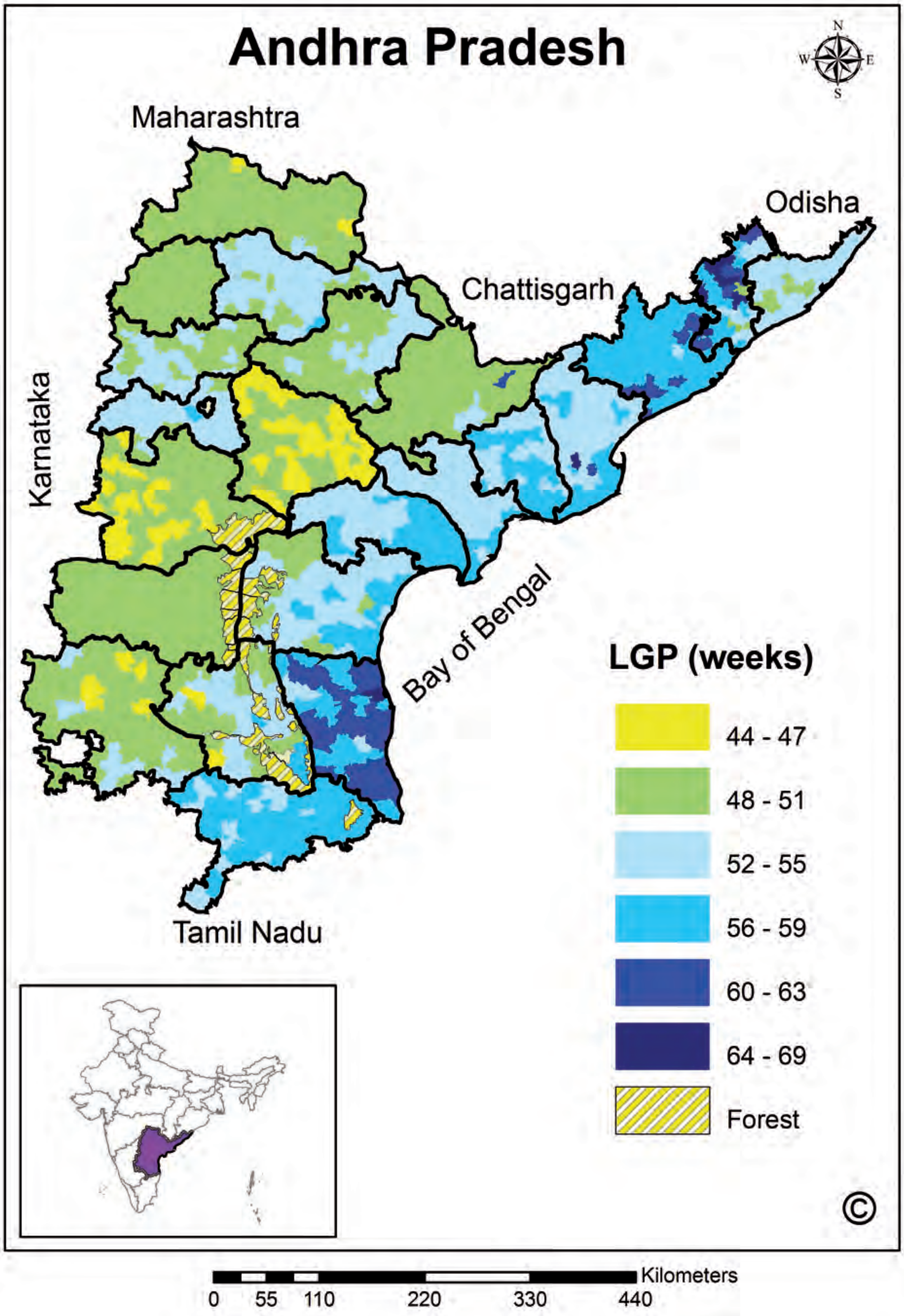


Fig. 90d: Termination of growing season (SMW) for soils having water holding capacity of 200 mm in Andhra Pradesh

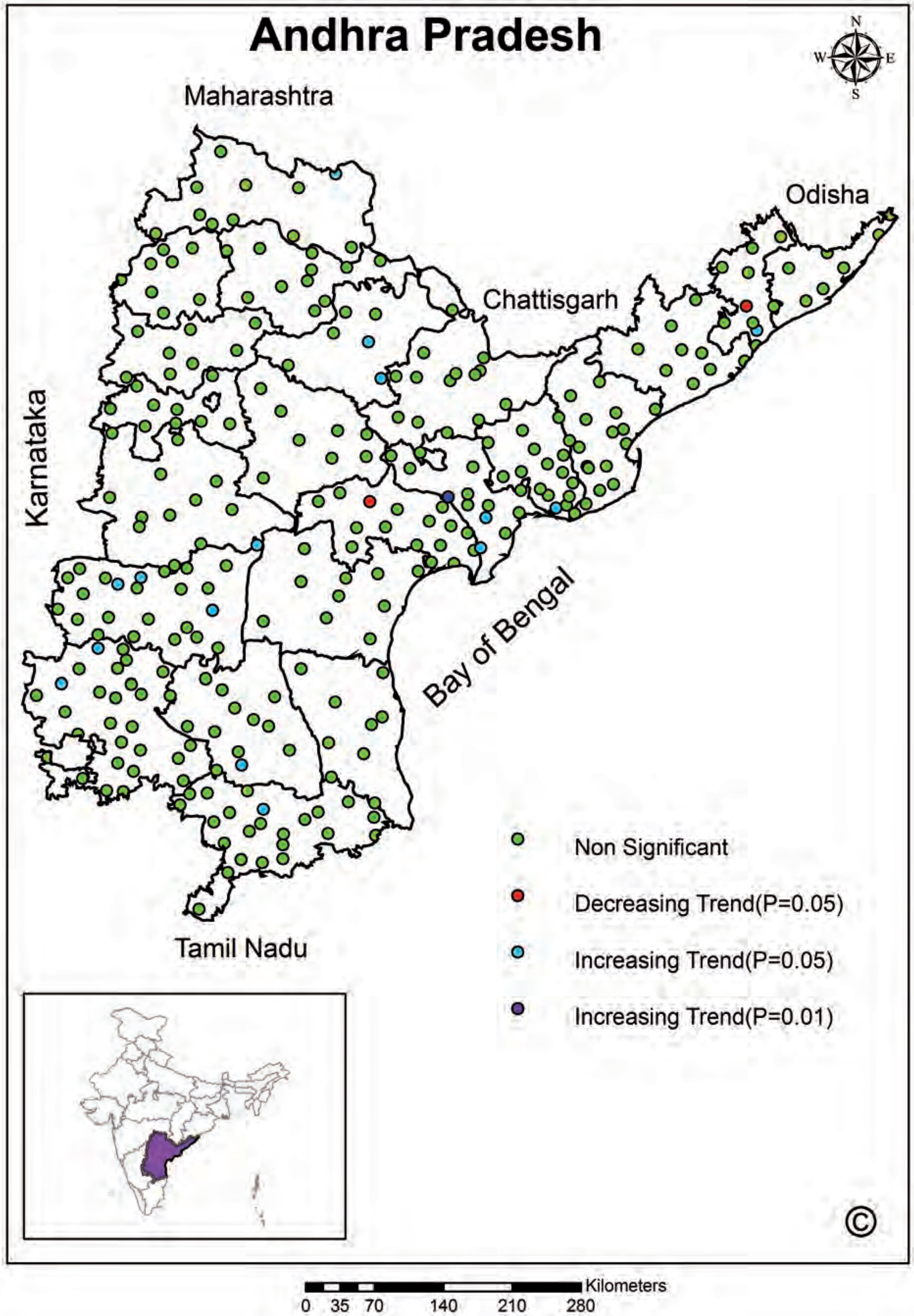


Fig. 91: Areas showing changes in maximum one-day rain episodes in Andhra Pradesh

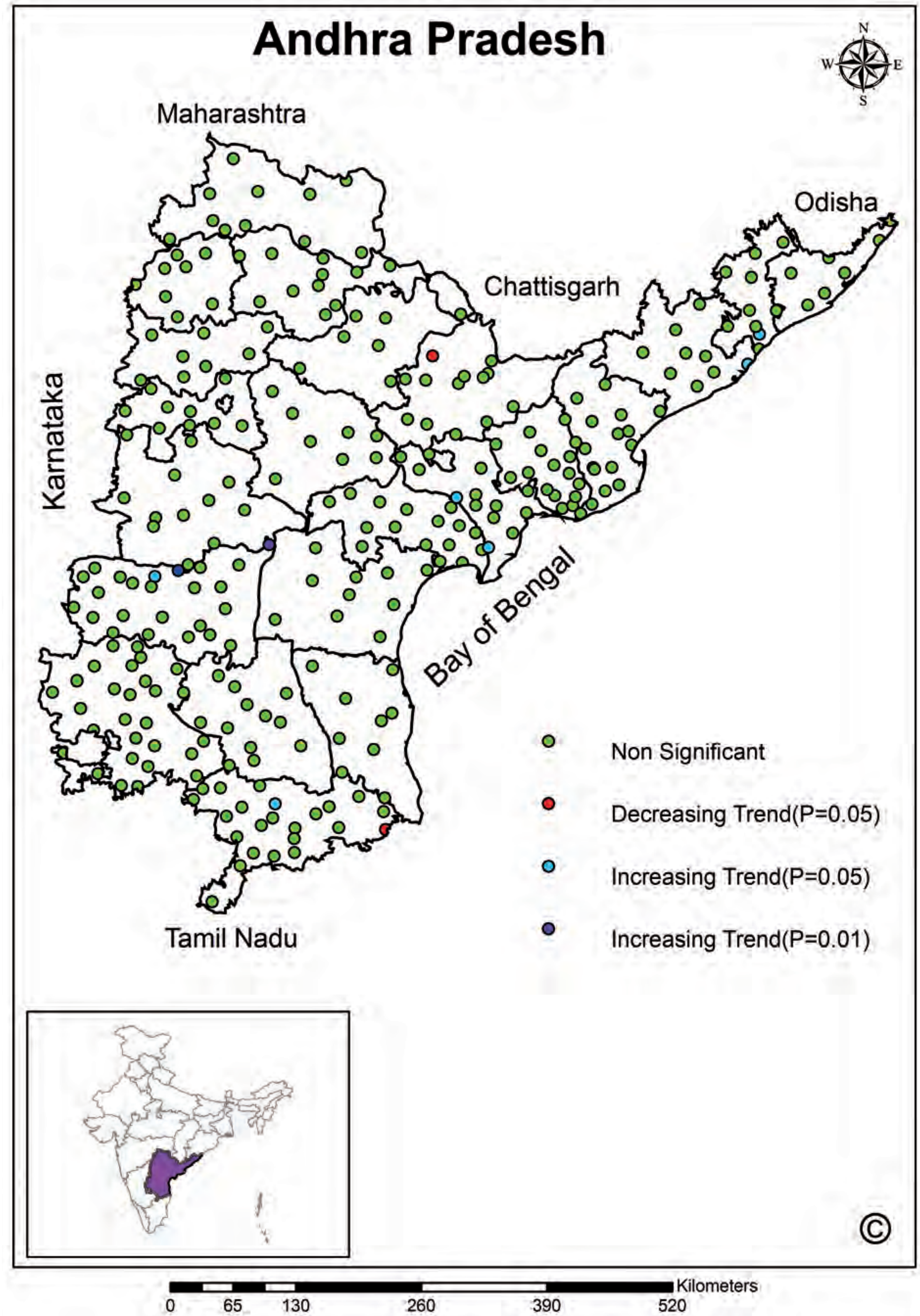


Fig. 92: Areas in Andhra Pradesh showing changes in maximum five-day total rainfall

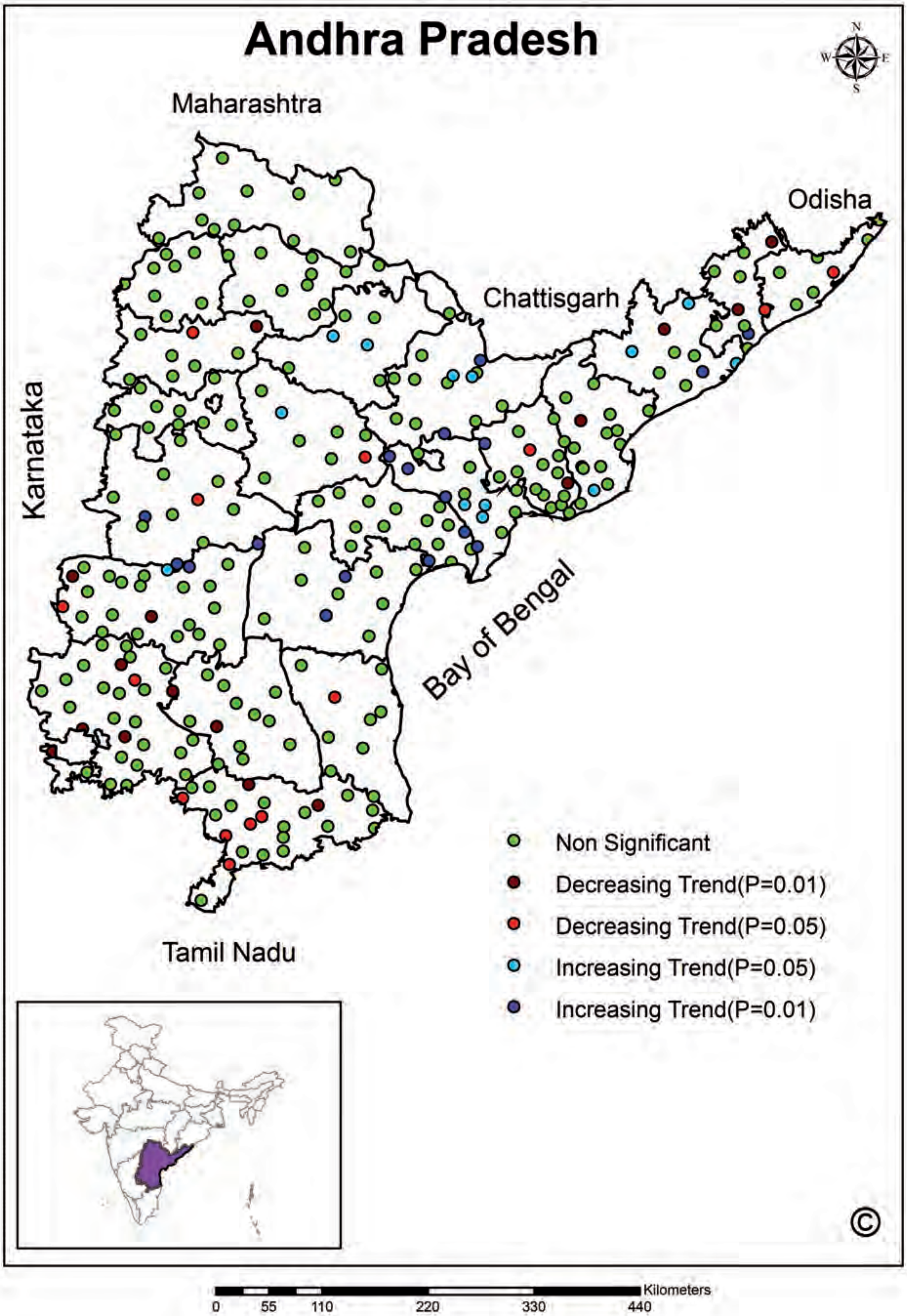


Fig. 93: Areas in Andhra Pradesh showing changes in mean daily rainfall intensity

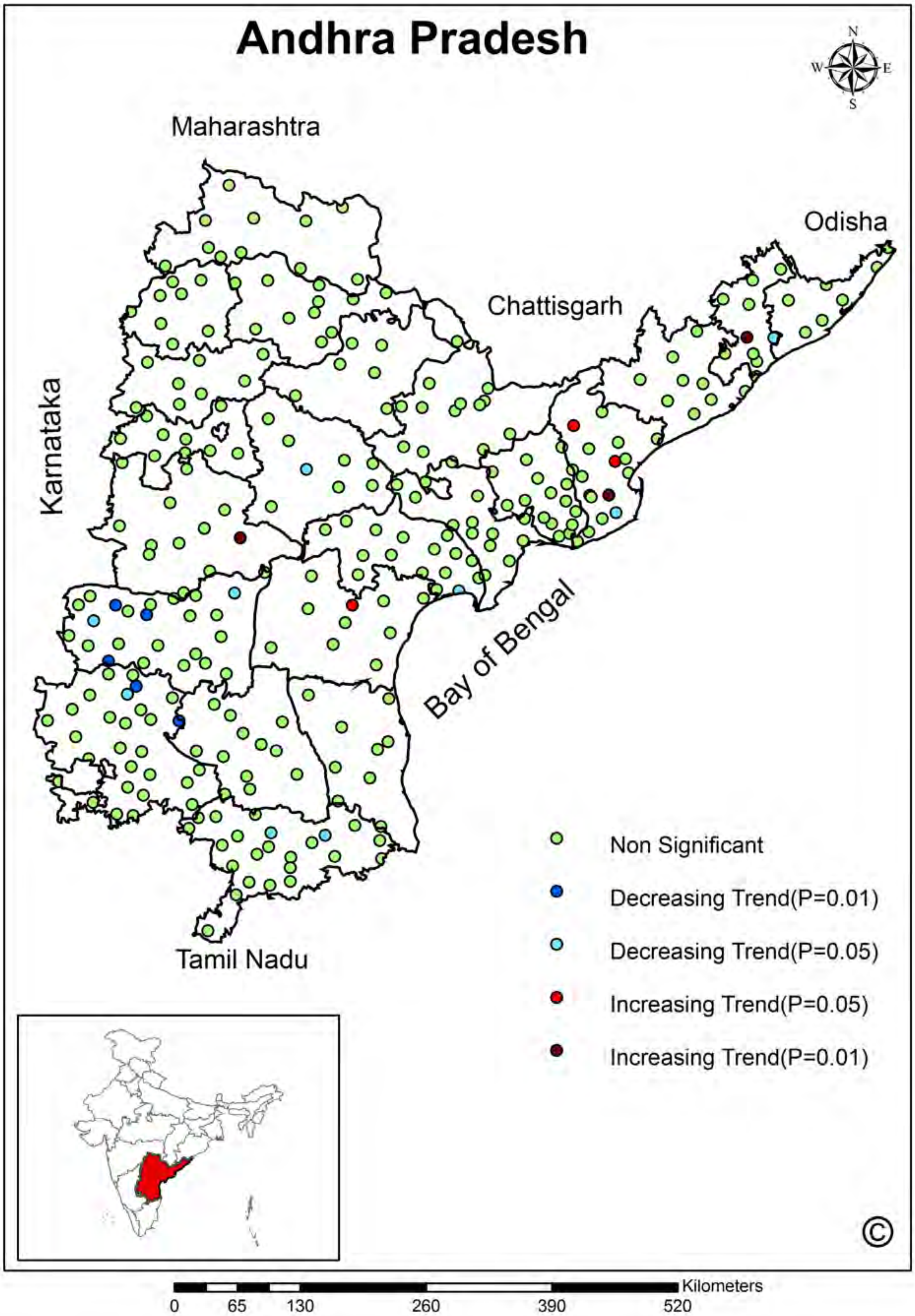


Fig. 94: Areas showing changes in maximum length of dry spell in Andhra Pradesh

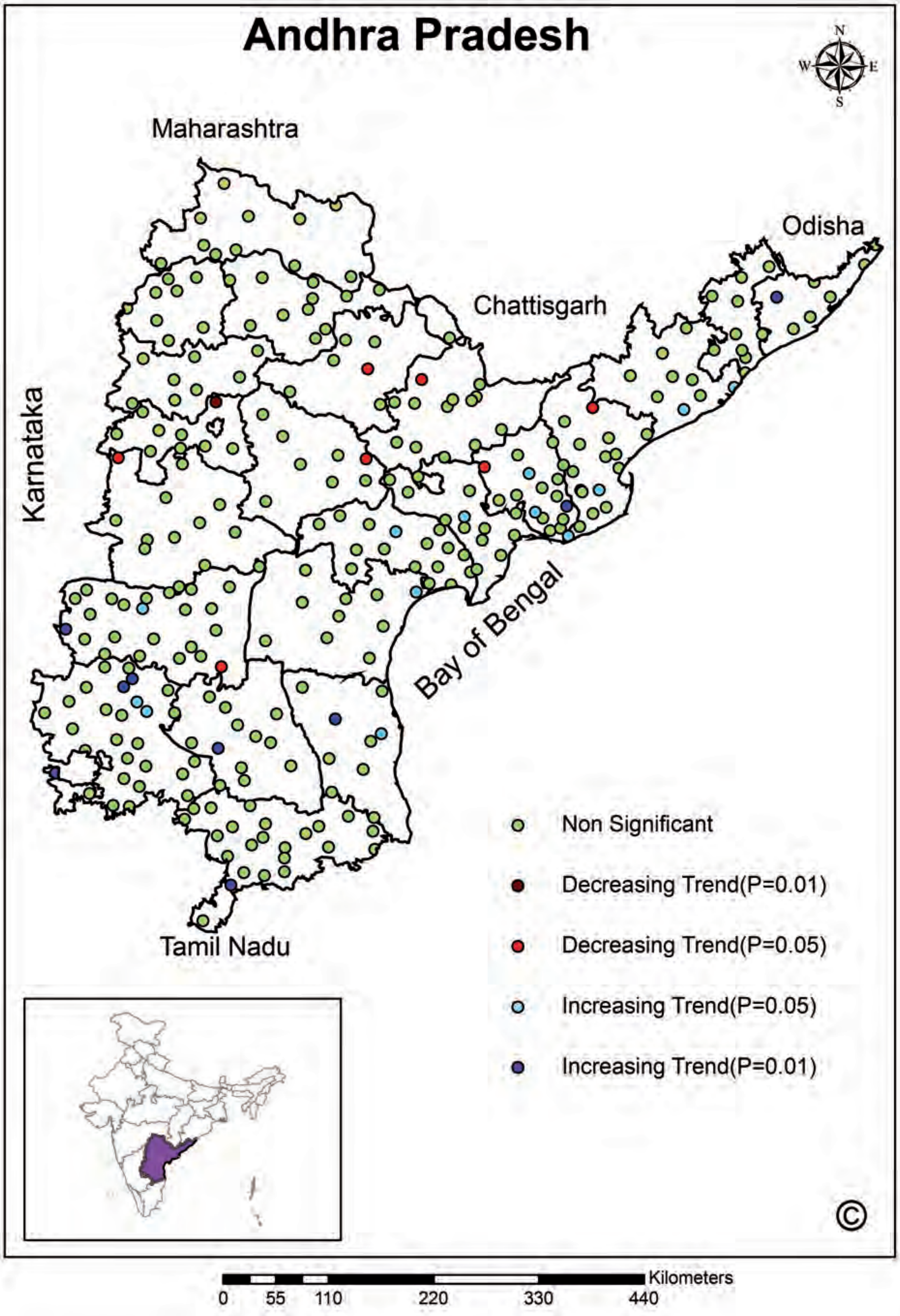


Fig. 95: Areas showing changes in maximum length of wet spells in Andhra Pradesh

5. Temperature

5.1. Maximum temperature

The mean annual temperature of the state is 33.2°C. A peak occurs during summer season (37.4°C) and the lowest temperature is recorded during NEM season (30.5°C). Average temperatures are ± 33.1°C during SWM season. Coastal Andhra region experiences relatively low temperatures during winter and summer seasons but higher temperatures during SWM and NEM seasons compared to the two other regions of the state. The spatial distribution of annual temperature (Fig. 96) shows a range of 31.5 to 35.5°C across various locations. Highest temperatures (34.5 to 35.5°C) are recorded in the northern parts of Adilabad and eastern parts of Kurnool district, and these are in the range of 31.5 to 32.5°C in parts of Srikakulam, East and West Godavari and western parts of Chittoor districts, whereas mean maximum temperatures in the remaining districts range from 32.5 to 34.5°C.

On a monthly basis, highest mean maximum temperature (39.0°C) is observed during in the month of May and lowest (29.5°C) during December (Table. 20). April and May months are the warmest in all the three regions of the state. On a district basis Kurnool district is the warmest district (34.7°C) followed by Prakasam district (34.4°C). On an annual basis, Visakhapatnam (32.1°C) and Srikakulam (32.2°C) districts are somewhat cooler.

Prakasam district experiences a warm climate during SWM period (35.6°C) followed by Guntur district (34.7°C), whereas Medak (31.2°C) and Ranga Reddy (31.4°C) districts experiences cool weather during the corresponding period (Fig. 97). Temperatures during NEM period are at the highest in Nalgonda district (31.9°C) followed by East Godavari (31.7°C) and lowest in Chittoor (28.5°C) followed by Ranga Reddy (29.4°C) (Fig. 98). District average temperatures during summer are highest in Adilabad (40.4°C) followed by Kurnool (39.7°C) districts and are least in Visakhapatnam (33.9°C) district (Fig. 99). Likewise, temperatures are highest in Kurnool (33.3°C) district followed by Nalgonda and SPSR Nellore (32.0°C) districts during the winter season (Fig. 100). Least temperatures (30.1°C) are recorded in Visakhapatnam and West Godavari districts during the winter season.

5.2. Minimum temperature

The state as a whole experiences a minimum temperature of 22.4°C on an annual basis. However, there are regional differences. The coastal region experiences higher temperatures (23.9°C) compared to the *Telangana* region (21.4°C). The spatial distribution of annual minimum temperature is depicted in Fig. 101. On the district basis, East Godavari records highest annual minimum temperatures of 24.9°C, followed by Prakasam district (24.7°C). On the other hand Medak (20.0°C) and Ranga Reddy (20.1°C) districts experiences relatively cooler temperatures.

On average monthly basis, the month of December is the coolest month in all the three regions of the state, but temperatures are high in the Coastal Andhra region (19.2°C) and are lowest in *Telangana* (15.1°C) (Table. 21). Minimum temperatures are high during the month of May over the entire state (26.6°C). The Coastal Andhra region records highest temperature (27.6°C). *Rayalaseema* region (25.7°C) experiences relatively lower minimum temperatures compared to the *Telangana* region (26.6°C) during May. Amongst the districts, East Godavari (29.0°C) followed by Prakasam (28.3°C) are the warmest during May and Anantapur (25.0°C) and Chittoor (25.2°C) are relatively cooler. During December, cooler temperatures prevails over Medak (13.3°C) followed by Nizamabad (13.7°C). At the same time, Prakasam (21.3°C) and SPSR Nellore (21.2°C) experience relatively higher temperatures.

Table. 20: District average mean monthly maximum temperatures (^{o}C) in Andhra Pradesh

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	NEM
Anantapur	30.3	33.0	36.6	38.6	37.7	34.9	33.1	32.2	32.2	31.0	29.9	29.4	33.3	31.7	37.6	33.1	30.1
Chittor	28.8	31.7	35.0	36.8	37.1	34.6	32.9	32.0	31.9	30.2	28.2	27.2	32.2	30.3	36.3	32.8	28.5
YSR Kadapa	29.3	32.3	35.1	38.2	38.7	35.2	32.4	31.2	31.5	30.7	31.8	28.6	32.9	30.8	37.4	32.6	30.4
Kurnool	31.8	34.9	38.3	40.3	40.5	36.7	34.1	32.8	32.9	32.6	31.4	30.6	34.7	33.3	39.7	34.1	31.5
Average for Rayalaseema	**30.1**	**33.0**	**36.2**	**38.5**	**38.5**	**35.4**	**33.1**	**32.1**	**32.1**	**31.1**	**30.3**	**28.9**	**33.3**	**31.5**	**37.7**	**33.2**	**30.1**
Hyderabad	29.9	32.5	36.0	38.6	39.5	35.0	31.6	30.2	31.2	31.6	30.4	29.6	33.0	31.2	38.0	32.0	30.5
Karimnagar	30.1	32.8	36.4	39.6	41.6	37.0	32.3	31.1	32.5	32.6	31.1	29.7	33.9	31.4	39.2	33.2	31.1
Khammam	30.3	32.9	35.7	38.1	40.4	36.6	32.7	31.6	32.7	32.2	31.1	29.9	33.7	31.6	38.1	33.4	31.0
Adilabad	29.9	33.7	37.5	41.4	42.4	37.4	31.2	30.8	32.3	32.7	30.4	29.5	34.1	31.8	40.4	32.9	30.9
Mahabubnagar	29.8	32.9	36.3	38.2	38.8	34.5	31.2	30.0	30.7	30.9	30.0	29.1	32.7	31.3	37.8	31.6	30.0
Medak	29.5	32.3	35.9	38.4	39.4	34.6	30.7	29.3	30.1	30.6	29.4	28.7	32.4	30.9	37.9	31.2	29.6
Nalgonda	31.2	32.7	35.3	37.3	38.6	35.8	33.8	32.8	33.4	32.7	32.0	30.9	33.9	32.0	37.1	33.9	31.9
Nizamabad	30.3	33.2	36.9	40.0	41.1	35.9	31.5	30.2	31.3	31.9	30.8	29.9	33.6	31.8	39.3	32.2	30.9
Ranga Reddy	29.1	31.9	35.2	37.6	39.3	34.5	30.9	29.7	30.5	30.6	29.3	28.5	32.3	30.5	37.4	31.4	29.4
Warangal	29.8	32.6	36.1	39.2	41.1	36.7	32.2	30.9	32.1	31.9	30.5	29.3	33.5	31.2	38.8	33.0	30.6
Average for Telangana	**30.0**	**32.7**	**36.1**	**38.8**	**40.2**	**35.8**	**31.8**	**30.7**	**31.7**	**31.7**	**30.5**	**29.5**	**33.3**	**31.4**	**38.4**	**32.5**	**30.6**
Srikakulam	29.7	31.1	34.2	34.7	35.6	33.9	32.2	31.7	32.1	32.3	30.2	29.3	32.2	30.4	34.8	32.5	30.6
Visakhapatnam	29.3	30.9	32.8	33.9	35.1	34.1	32.3	32.1	32.3	31.7	30.7	29.4	32.1	30.1	33.9	32.7	30.6
Vizianagaram	29.7	32.3	35.7	37.7	38.2	35.5	33.8	32.3	32.8	31.7	30.7	29.4	33.3	31.0	37.2	33.6	30.6
West Godavari	29.0	31.1	33.2	35.1	37.3	35.6	32.4	31.3	31.7	31.1	30.2	29.1	32.3	30.1	35.2	32.7	30.1
East Godavari	29.2	31.0	33.5	35.6	37.9	36.0	32.5	31.9	32.4	31.8	30.7	32.5	32.9	30.1	35.7	33.2	31.7
Guntur	30.9	33.0	35.4	37.5	39.6	37.2	34.5	33.5	33.6	32.5	31.5	30.2	34.1	31.9	37.5	34.7	31.4
Krishna	30.1	32.4	35.2	37.4	39.7	37.2	33.9	32.7	33.0	32.2	31.1	30.0	33.7	31.3	37.4	34.2	31.1
SPSR Nellore	30.9	33.1	34.7	36.1	37.8	36.7	34.6	33.2	33.0	31.1	30.0	29.9	33.4	32.0	36.2	34.4	30.3
Prakasam	30.2	32.6	35.4	37.5	40.8	38.0	35.5	34.7	34.2	32.9	31.1	30.1	34.4	31.4	37.9	35.6	31.4
Average for Coastal Andhra	**29.9**	**32.0**	**34.5**	**36.2**	**38.0**	**36.0**	**33.5**	**32.6**	**32.8**	**31.9**	**30.7**	**30.0**	**33.2**	**30.9**	**36.2**	**33.7**	**30.9**

Table 21: District average mean monthly minimum temperatures (°C) in Andhra Pradesh

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	NEM
Anantapur	18.7	22.6	22.3	24.9	25.0	23.9	23.2	23.0	22.8	21.5	19.5	17.4	22.1	20.6	24.1	23.2	19.5
Chittor	16.0	17.9	20.4	23.7	25.2	24.7	23.7	23.4	22.8	21.3	19.3	16.9	21.3	16.9	23.1	23.6	19.2
YSR Kadapa	16.3	18.1	20.7	24.5	25.5	23.4	23.1	22.3	22.0	21.5	18.3	15.9	21.0	17.2	23.6	22.7	18.6
Kurnool	17.3	19.7	22.9	26.0	27.2	25.5	24.4	24.0	23.8	22.9	20.0	17.3	22.6	18.5	25.4	24.4	20.0
Average for Rayalaseema	**17.1**	**19.6**	**21.6**	**24.8**	**25.7**	**24.3**	**23.6**	**23.2**	**22.9**	**21.8**	**19.2**	**16.9**	**21.7**	**18.3**	**24.0**	**23.5**	**19.3**
Adilabad	14.3	18.2	21.4	25.3	28.0	26.1	24.0	23.8	23.7	21.3	18.1	14.2	21.5	16.3	24.9	24.4	17.8
Hyderabad	15.5	18.3	21.2	24.5	26.0	24.2	22.8	22.4	22.3	20.8	17.5	14.7	20.9	16.9	23.9	22.9	17.7
Karimnagar	15.3	17.9	21.0	24.7	27.6	26.6	24.5	23.9	23.8	21.5	17.1	14.0	21.5	16.6	24.5	24.7	17.5
Khammam	17.0	19.9	22.4	25.1	26.6	25.3	24.0	23.7	23.8	22.6	19.3	16.5	22.2	18.5	24.7	24.2	19.5
Mahabubnagar	15.5	17.8	21.2	24.6	26.2	24.3	23.0	22.4	22.3	20.9	18.2	15.5	21.0	16.6	24.0	23.0	18.2
Medak	14.4	16.8	20.0	23.2	25.3	24.1	22.7	22.1	21.8	19.7	16.0	13.3	20.0	15.6	22.8	22.7	16.4
Nalgonda	19.5	20.8	22.9	25.0	26.3	25.3	24.9	24.1	24.2	23.4	20.9	19.0	23.0	20.2	24.7	24.6	21.1
Nizamabad	15.0	17.8	21.0	24.8	27.0	25.1	23.5	22.9	22.8	20.5	16.6	13.7	20.9	16.4	24.3	23.6	17.0
Ranga Reddy	14.5	16.9	20.1	23.3	25.6	24.0	22.5	21.8	21.6	19.9	16.8	14.1	20.1	15.7	23.0	22.5	16.9
Warangal	17.0	19.7	22.6	25.2	27.6	26.6	24.9	24.4	24.4	22.9	19.6	16.2	22.6	18.4	25.1	25.1	19.6
Average for Telangana	**15.8**	**18.4**	**21.4**	**24.6**	**26.6**	**25.2**	**23.7**	**23.1**	**23.1**	**21.3**	**18.0**	**15.1**	**21.4**	**17.1**	**24.2**	**23.8**	**18.2**
East Godavari	19.9	21.6	24.5	27.4	29.0	28.3	26.6	26.4	26.5	25.2	22.7	20.3	24.9	20.8	27.0	26.9	22.7
Guntur	18.6	23.1	23.5	26.2	27.7	27.3	26.0	25.3	25.1	23.9	21.6	19.0	23.9	20.9	25.8	25.9	21.5
Krishna	18.4	20.2	22.5	25.4	27.3	26.8	25.3	25.0	24.8	23.7	21.1	18.6	23.3	19.3	25.0	25.5	21.1
SPSR Nellore	21.3	22.8	24.4	26.1	27.5	27.4	26.2	25.5	24.7	23.6	22.1	21.2	24.4	22.0	26.0	26.0	22.3
Prakasam	20.9	22.2	24.2	26.6	28.3	27.8	26.7	25.6	25.5	24.4	23.1	21.3	24.7	21.6	26.3	26.4	22.9
Srikakulam	17.2	19.2	23.1	26.4	27.1	26.8	26.3	25.6	25.5	24.4	20.5	16.4	23.2	18.2	25.5	26.0	20.4
Visakhapatnam	18.5	20.1	22.9	25.4	26.8	26.7	25.7	25.4	25.2	23.9	21.5	18.9	23.4	19.3	25.0	25.7	21.4
Vizianagaram	17.9	20.4	23.7	26.5	27.3	27.0	26.4	25.9	25.8	24.5	20.4	17.3	23.6	19.1	25.8	26.3	20.7
West Godavari	19.8	20.9	22.9	25.6	27.4	27.1	25.9	25.5	25.6	24.5	22.0	19.7	23.9	20.3	25.3	26.0	22.1
Average for Coastal Andhra	**19.2**	**21.2**	**23.5**	**26.2**	**27.6**	**27.2**	**26.1**	**25.6**	**25.4**	**24.2**	**21.7**	**19.2**	**23.9**	**20.2**	**25.8**	**26.1**	**21.7**

During the SWM season, Coastal Andhra experiences high minimum temperatures of 26.1°C which are the higher over other two regions and during all the three seasons. This is due to presence of prolonged cloudy conditions (Fig. 102). *Rayalseema* regions experiences slightly lower temperatures compared to the *Telangana* region. On the district basis, East Godavari (26.9°C) followed by Prakasam (26.4°C) experience higher temperatures, whereas Ranga Reddy (22.5°C) and Medak (22.7°C) experience lower temperatures during the SWM period. The mean seasonal temperatures for NEM period on a regional basis are higher over Coastal Andhra (21.7°C) and are least in *Telangana* region (18.2°C) (Fig. 103). During this season Prakasam (22.9°C) and East Godavari (22.7°C) experience higher minimum temperatures compared to other districts. Lower temperatures are recorded in Medak (16.4°C) followed by Ranga Reddy (16.9°C) districts.

During the summer season minimum temperatures are high over the Coastal Andhra (25.8°C) and are low over *Rayalaseema* (24.0°C) region (Fig. 104). East Godavari (27.0°C) followed by Prakasam (26.3°C) are the warmest districts during this season. Whereas, Chittoor (23.1°C) and Medak (22.8°C) the cooler. On the contrary, *Telangana* region experiences cool temperatures compared to other two regions (Fig. 105). SPSR Nellore (22.0°C) and Prakasam (21.6°C) are the warmest districts during the winter season. Medak (15.6°C) and Ranga Reddy (15.7°C) are the cooler districts during the winter season.

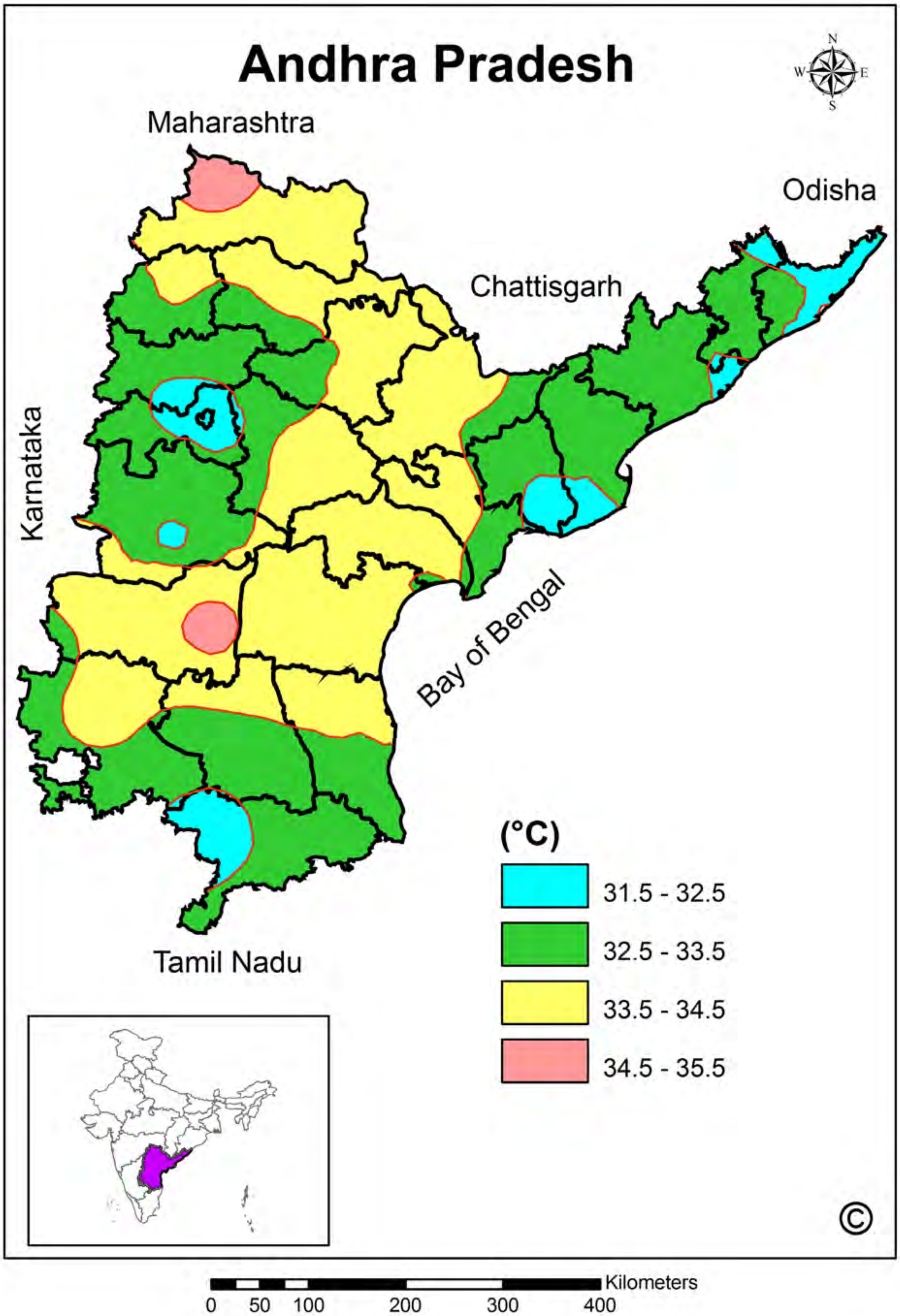


Fig. 96: Spatial distribution of annual mean maximum temperature in Andhra Pradesh

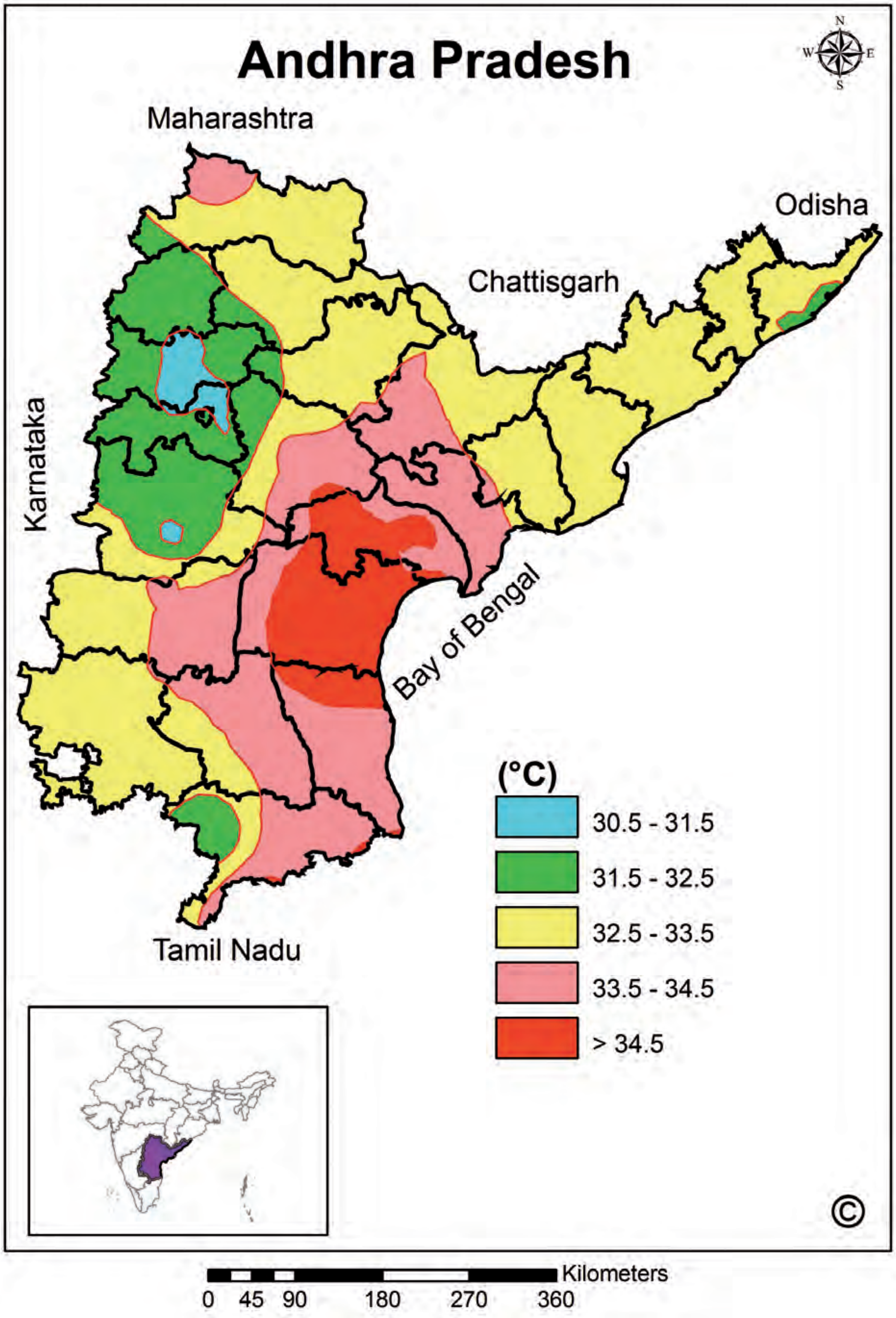


Fig. 97: Spatial distribution of mean Southwest monsoon season maximum temperature in Andhra Pradesh

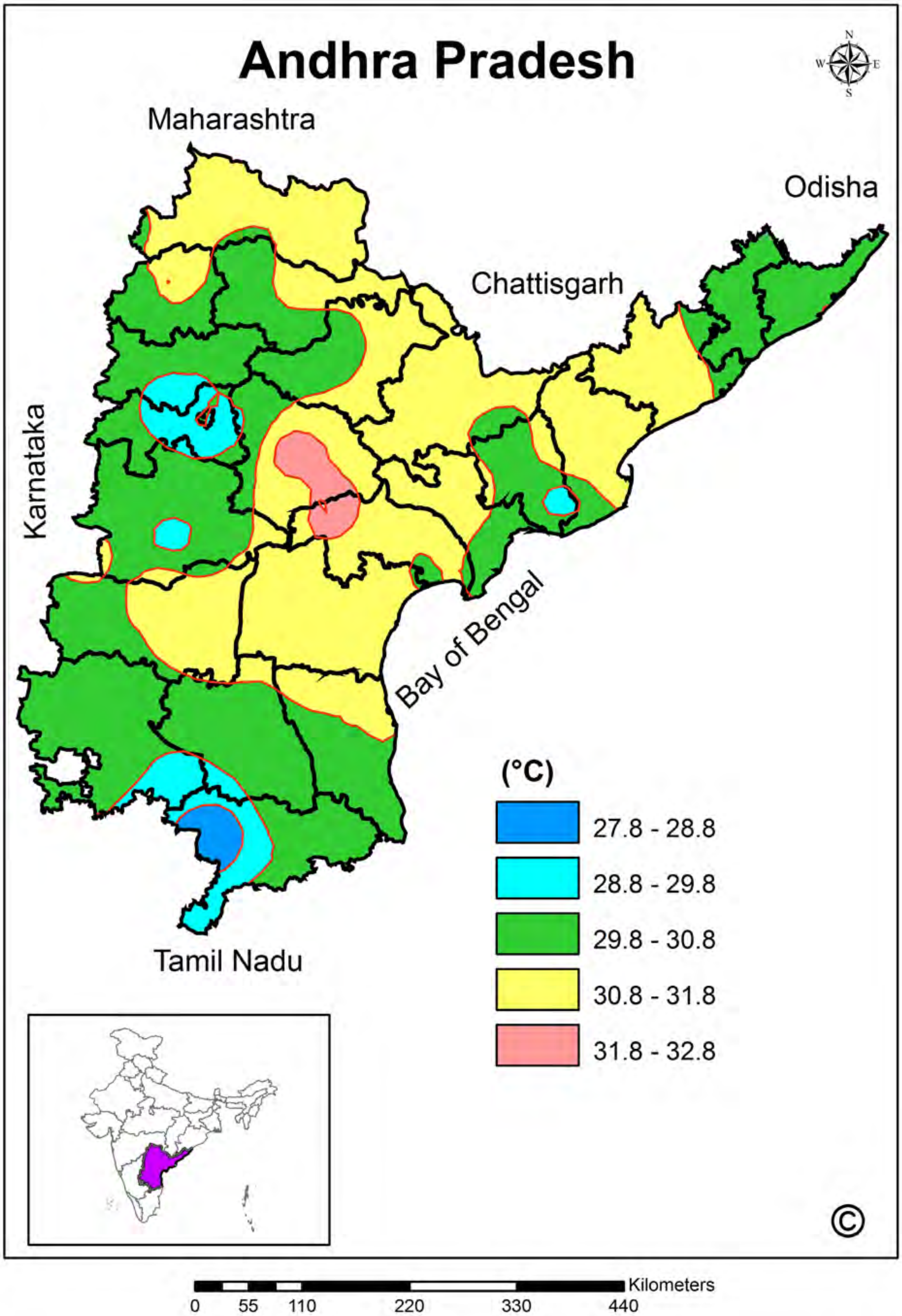


Fig. 98: Spatial distribution of mean Northeast monsoon season maximum temperature in Andhra Pradesh

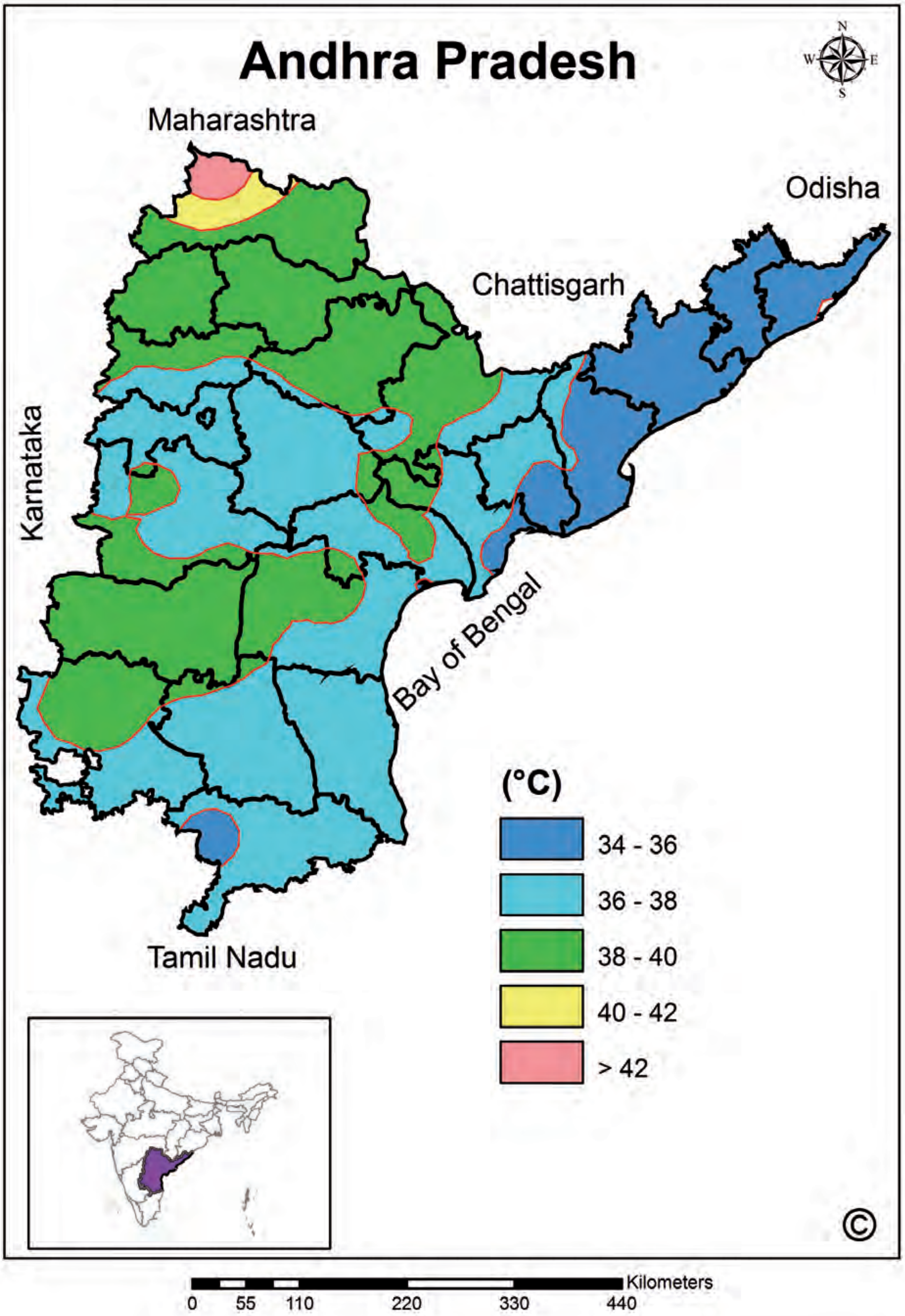


Fig. 99: Spatial distribution of mean summer season maximum temperature in Andhra Pradesh

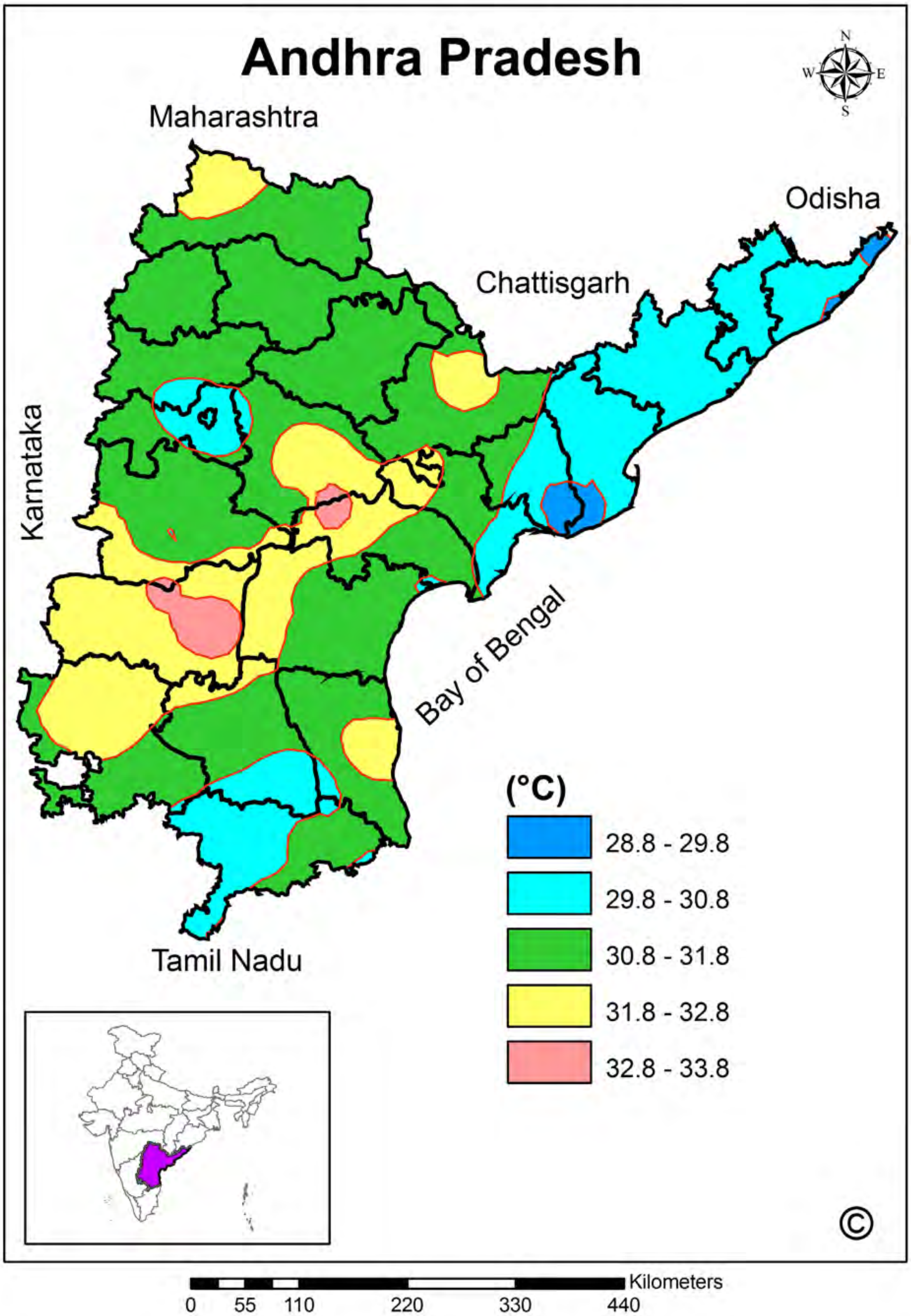


Fig. 100: Spatial distribution of mean winter season maximum temperature in Andhra Pradesh

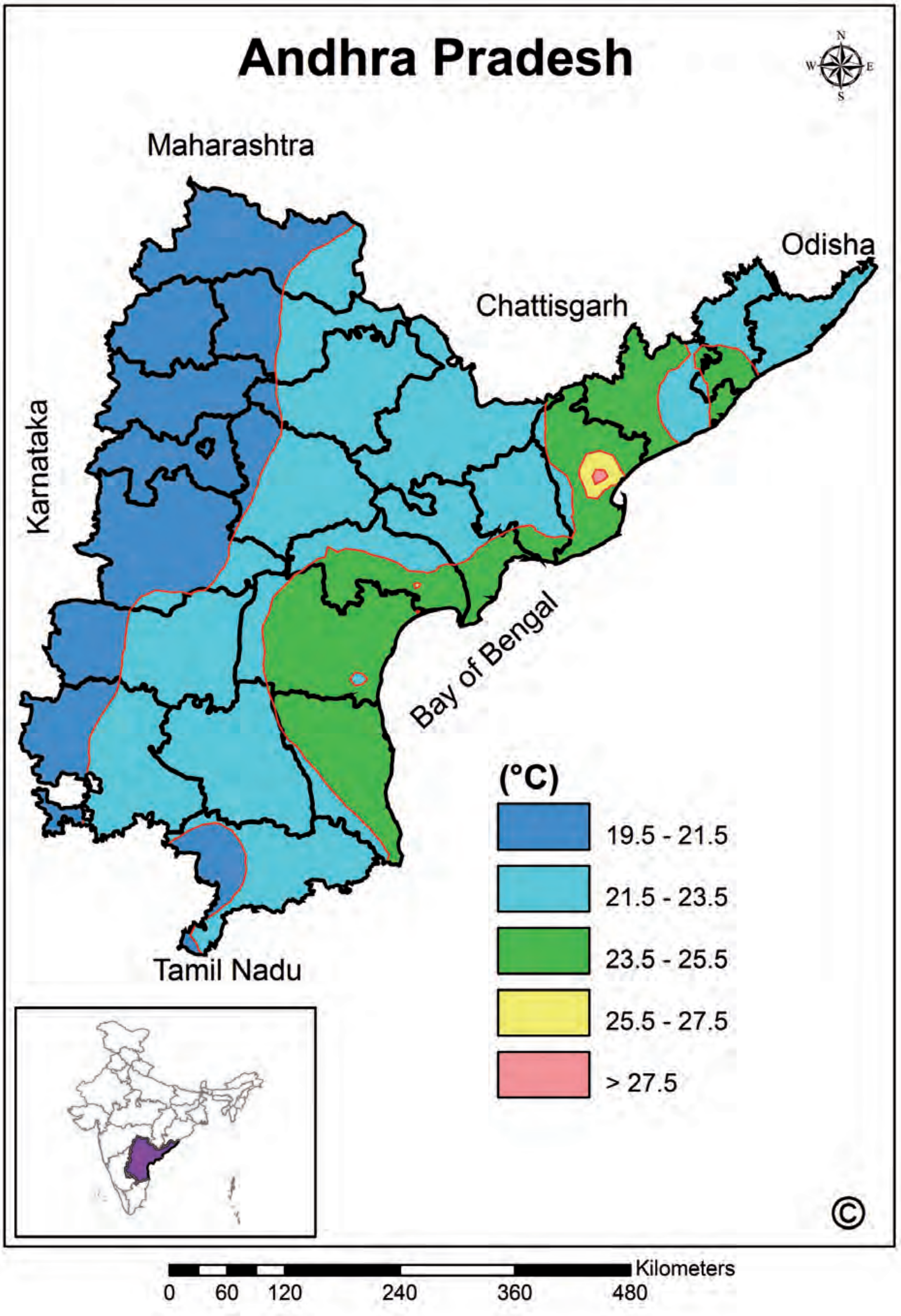


Fig. 101: Annual mean minimum temperatures in Andhra Pradesh

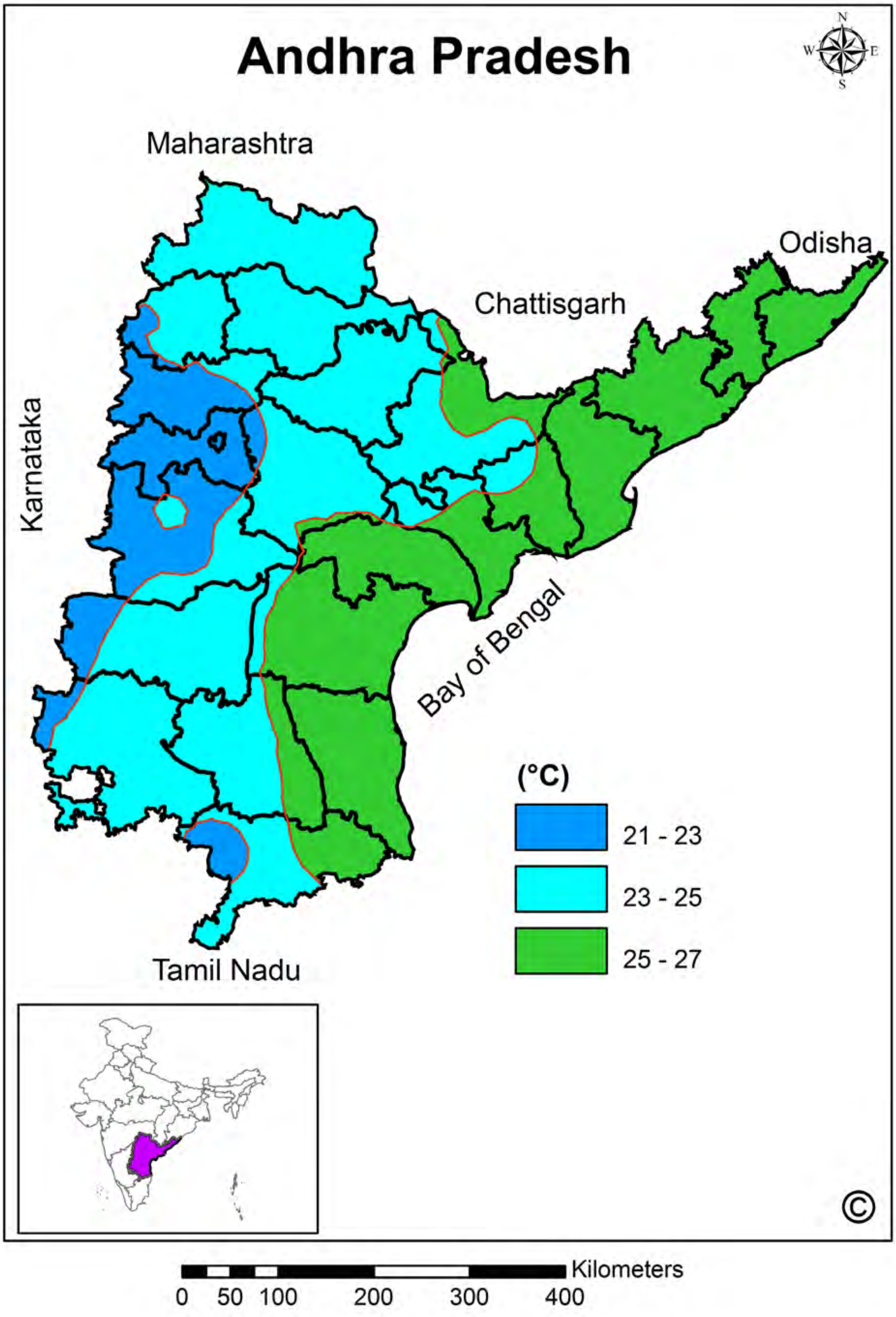


Fig. 102: Mean Southwest monsoon season minimum temperatures in Andhra Pradesh

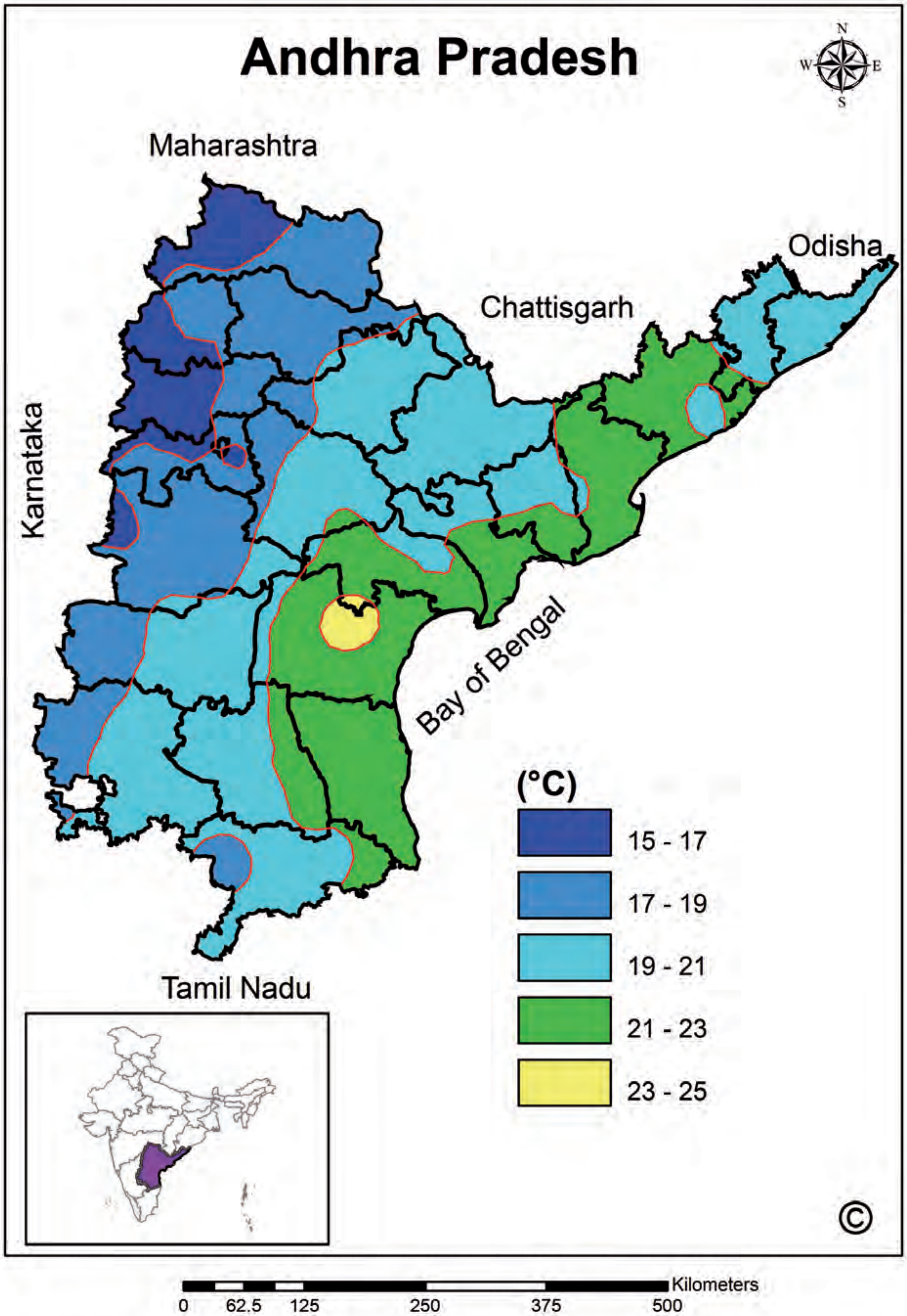


Fig. 103: Mean Northeast monsoon season minimum temperatures in Andhra Pradesh

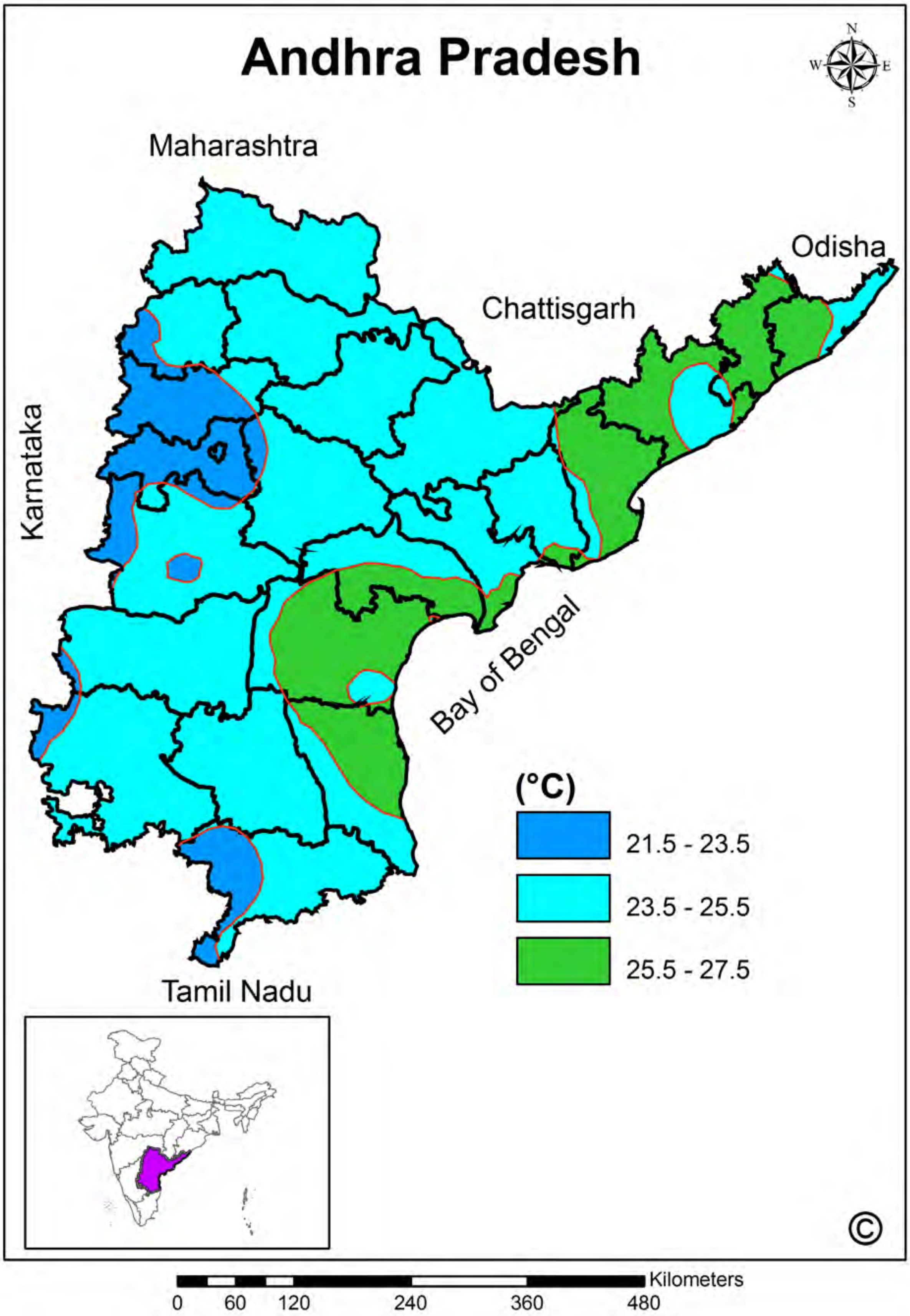


Fig. 104: Mean summer season minimum temperatures in Andhra Pradesh

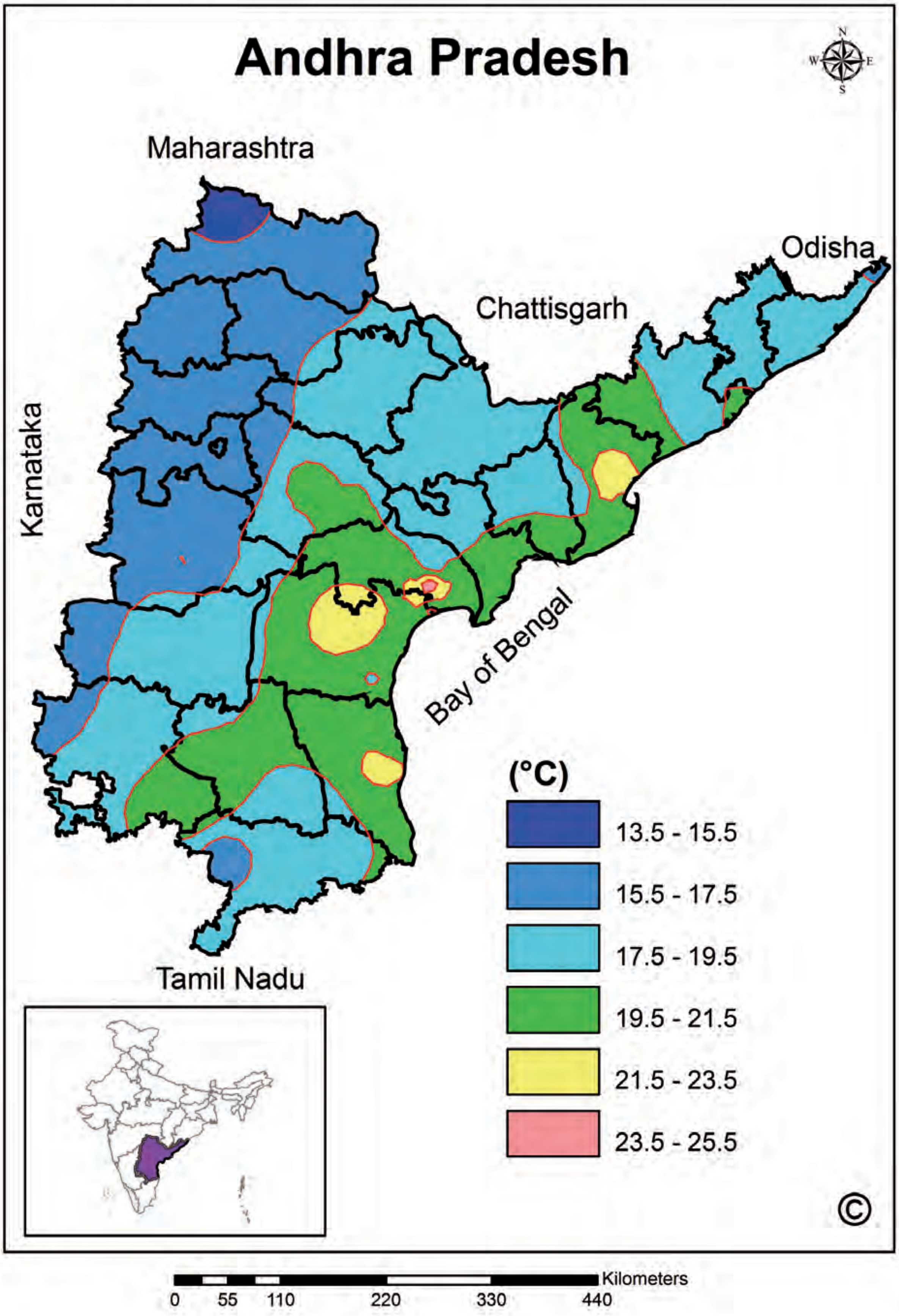


Fig. 105: Mean winter season minimum temperatures in Andhra Pradesh

6. Relative Humidity

6.1. Morning Relative Humidity over the state of Andhra Pradesh

On an annual basis the state of Andhra Pradesh experiences 78% relative humidity in the morning. Regional differences exist. In the Coastal region, the relative humidity is 84%. It is higher than the other two regions. *Rayalaseema* region is the driest region with a RH of 74%. Amongst the districts, Visakhapatnam (88%) and Srikakulam (87%) are the most humid and Adilabad (66%) and Karimnagar (72%) are least humid (Fig. 106).

On monthly basis, state as a whole experiences high morning humidity during October (84%) and least humidity is recorded during May (66%) (Table. 22). Regional differences do exist. The morning RH is different in various months. *Telangana* region (60%) is the least humid during May, January (79%) and February months compared to the other regions. Amongst the districts, Adilabad (49%) is the least humid during May, followed by the Karimnagar (50%) district. Higher humidity during this month is recorded in Visakhapatnam (84%) followed by Srikakulam (83%) districts.

During the SWM season the mean morning RH of the state is 79%. The Coastal Andhra records a higher value of 83%. Least morning RH prevails over *Rayalaseema* (72%) (Fig. 107). Amongst the districts, Srikakulam (88%) and Visakhapatnam (87%) are the most humid, whereas Adilabad (70%) followed by YSR Kadapa (73%) are least humid. The *Rayalaseema* regions turns humid at par with *Telangana* with 82% humidity during the NEM season. However, Coastal Andhra region continuous to be at the top with 86% humidity (Fig. 108). During the NEM season, SPSR Nellore district experience high morning humidity (92%) which is primarily due to the influence of NEM rains. Driest district during this NEM season is Adilabad with a RH of 73%.

Summer is the season in Andhra Pradesh during which lowest morning RH values (70%) are recorded. *Rayalaseema* and *Telangana* regions are almost on par regarding the summer season RH, but Coastal Andhra region experiences relatively high morning RH (Fig. 109). In the Coastal districts, Visakhapatnam (87%) followed by Srikakulam (84%) tops the list. Whereas, Karimnagar and Adilabad with 56% each are at the bottom. During the winter season, morning RH is more over the *Rayalaseema* (80%) region compared to the *Telangana* region (77%). Coastal Andhra region (86%) nevertheless, experience a high RH. Season, as a whole winter is more humid compared to summer in all the three regions (Fig. 110). Visakhapatnam (91%) and Guntur (89%) in Coastal Andhra are the districts which are most humid during winter, whereas Adilabad (65%) and Nizamabad (71%) are the least humid districts.

Table 22: District average mean monthly morning relative humidity (%) in Andhra Pradesh

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Sum-mer	SWM	NEM
Anantapur	79	71	61	57	61	69	74	77	79	80	81	82	73	75	60	75	81
Chittor	83	78	70	69	62	62	67	70	74	82	84	84	74	80	67	68	83
YSR Kadapa	83	84	75	64	63	66	74	75	78	81	83	81	76	84	67	73	82
Average for Rayalaseema	**82**	**78**	**69**	**63**	**62**	**66**	**72**	**74**	**77**	**81**	**83**	**82**	**74**	**80**	**65**	**72**	**82**
Adilabad	63	67	65	53	49	55	72	76	76	76	74	70	66	65	56	70	73
Karimnagar	78	72	63	56	50	68	80	83	83	80	76	76	72	75	56	78	77
Khammam	75	76	77	75	70	73	81	84	82	82	80	78	78	76	74	80	80
Mahabubnagar	86	81	73	69	67	80	87	90	90	88	86	85	82	84	70	87	86
Medak	89	79	69	63	58	78	87	90	91	90	89	89	81	84	64	87	89
Nizamabad	76	66	56	52	51	73	84	86	87	84	81	79	73	71	53	82	82
Ranga Reddy	87	81	74	70	67	80	86	89	88	87	88	87	82	84	70	86	87
Warangal	81	81	75	76	67	72	81	84	83	83	83	80	79	81	73	80	82
Average for Telangana	**79**	**75**	**69**	**64**	**60**	**72**	**82**	**85**	**85**	**84**	**82**	**81**	**77**	**77**	**64**	**81**	**82**
East Godavari	82	80	79	79	73	76	84	86	88	85	82	79	81	81	77	83	82
Guntur	90	88	86	82	74	74	81	83	85	88	88	88	84	89	80	81	88
SPSR Nellore	89	82	78	77	76	77	82	85	87	91	92	92	84	85	77	82	92
Prakasam	87	87	88	85	77	77	80	80	83	86	87	87	84	87	83	80	87
Srikakulam	87	89	87	82	83	85	88	89	89	90	89	88	87	88	84	88	89
Visakhapatnam	91	91	90	87	84	83	88	88	91	90	87	88	88	91	87	87	88
Vizianagaram	83	81	78	75	73	74	79	82	83	82	75	77	79	82	75	80	78
West Godavari	84	85	84	83	80	81	85	86	86	86	83	83	84	85	82	84	84
Average for Coastal Andhra	**87**	**85**	**84**	**81**	**77**	**78**	**83**	**85**	**87**	**87**	**85**	**85**	**84**	**86**	**81**	**83**	**86**

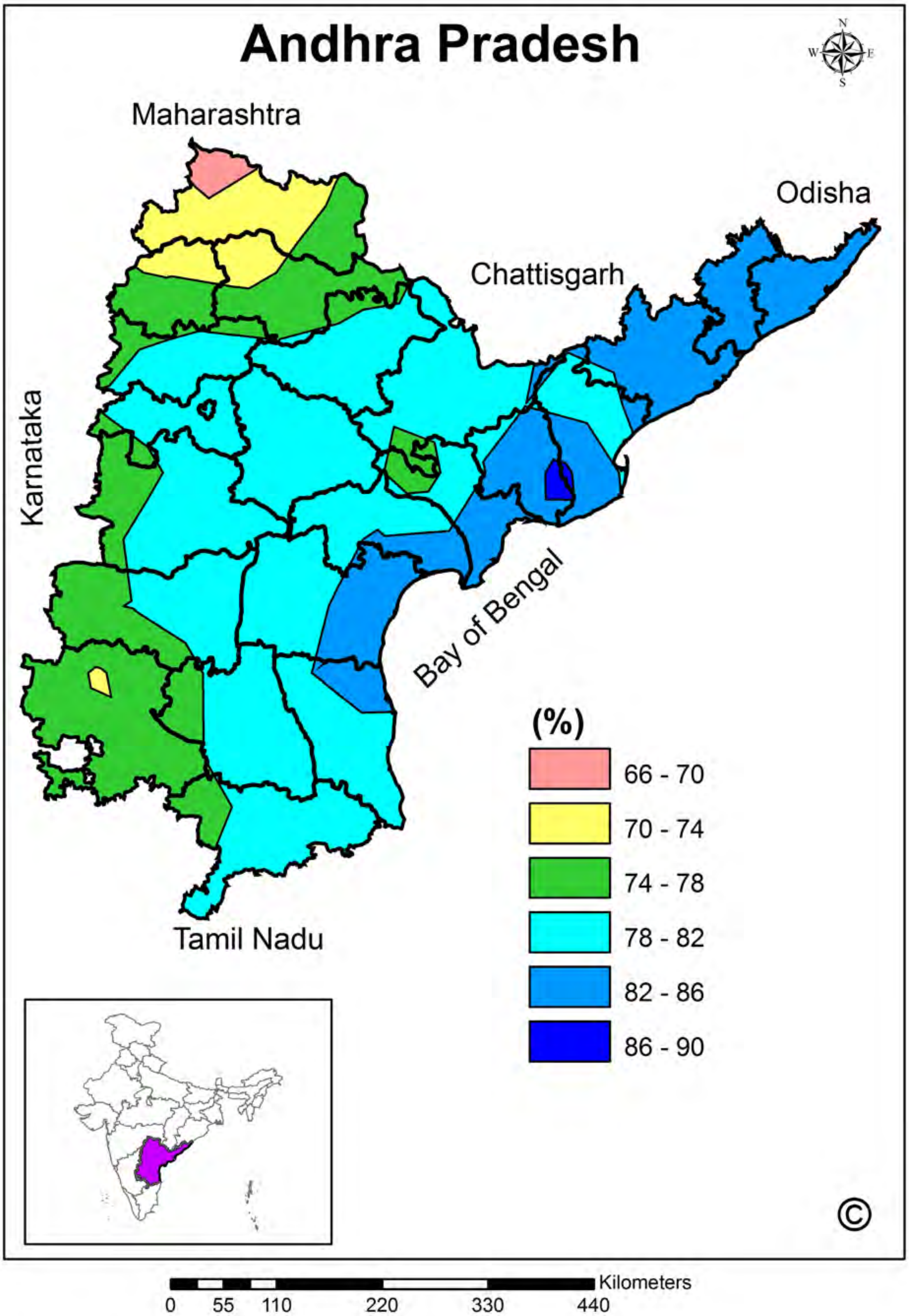


Fig. 106: Mean annual morning relative humidity in Andhra Pradesh

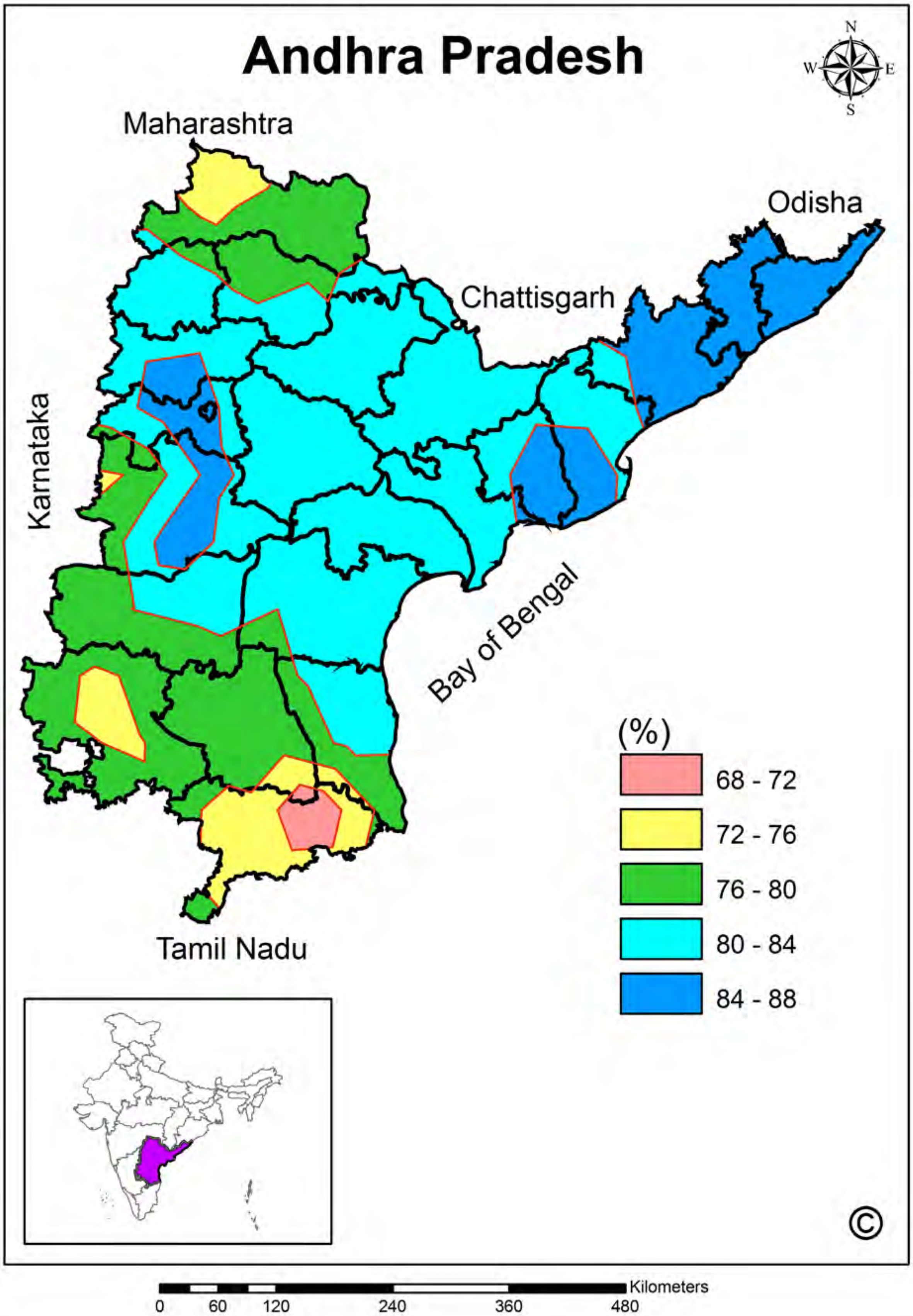


Fig. 107: Mean morning relative humidity during the Southwest monsoon season in Andhra Pradesh

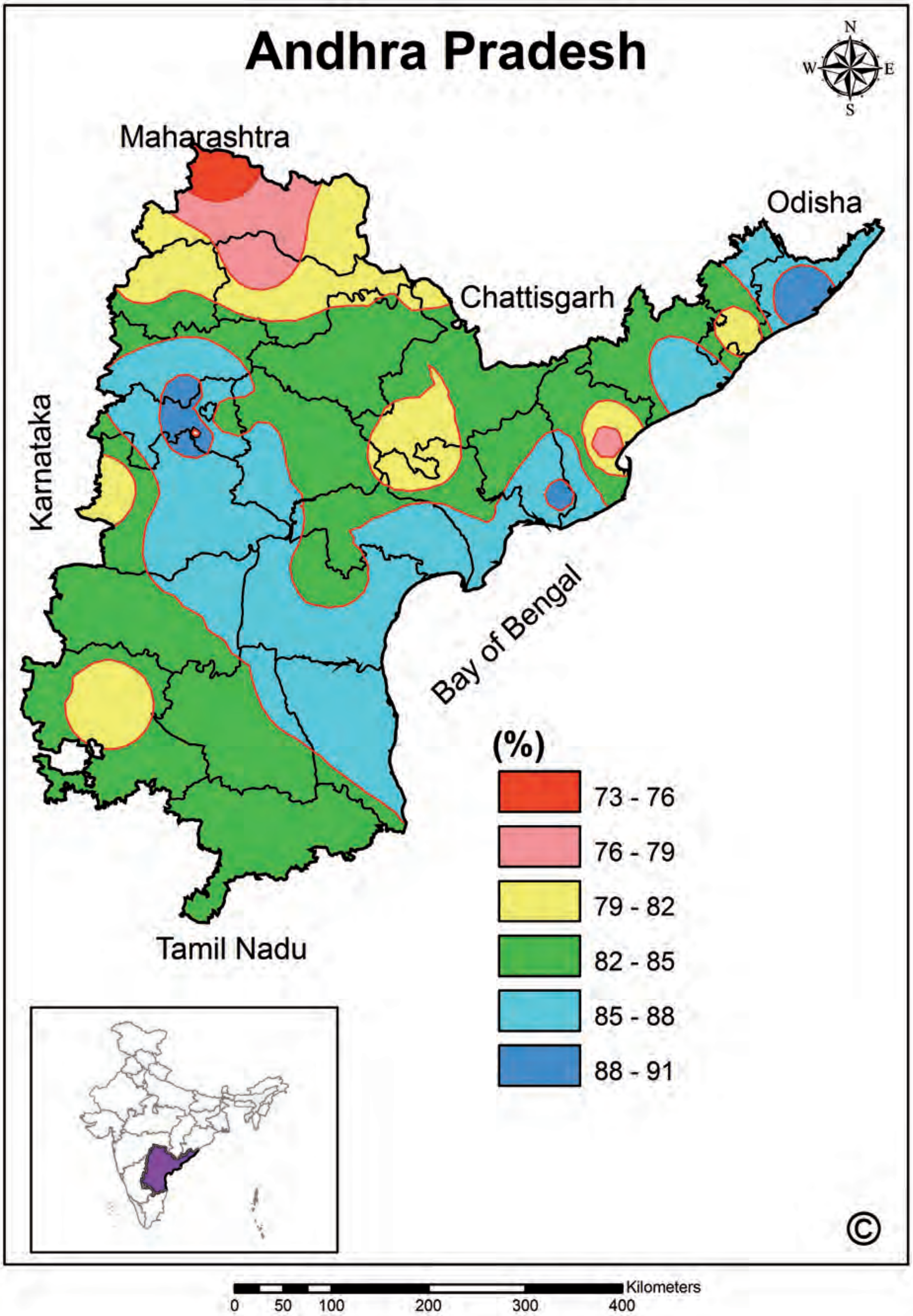


Fig. 108: Mean morning relative humidity during the Northeast monsoon season in Andhra Pradesh

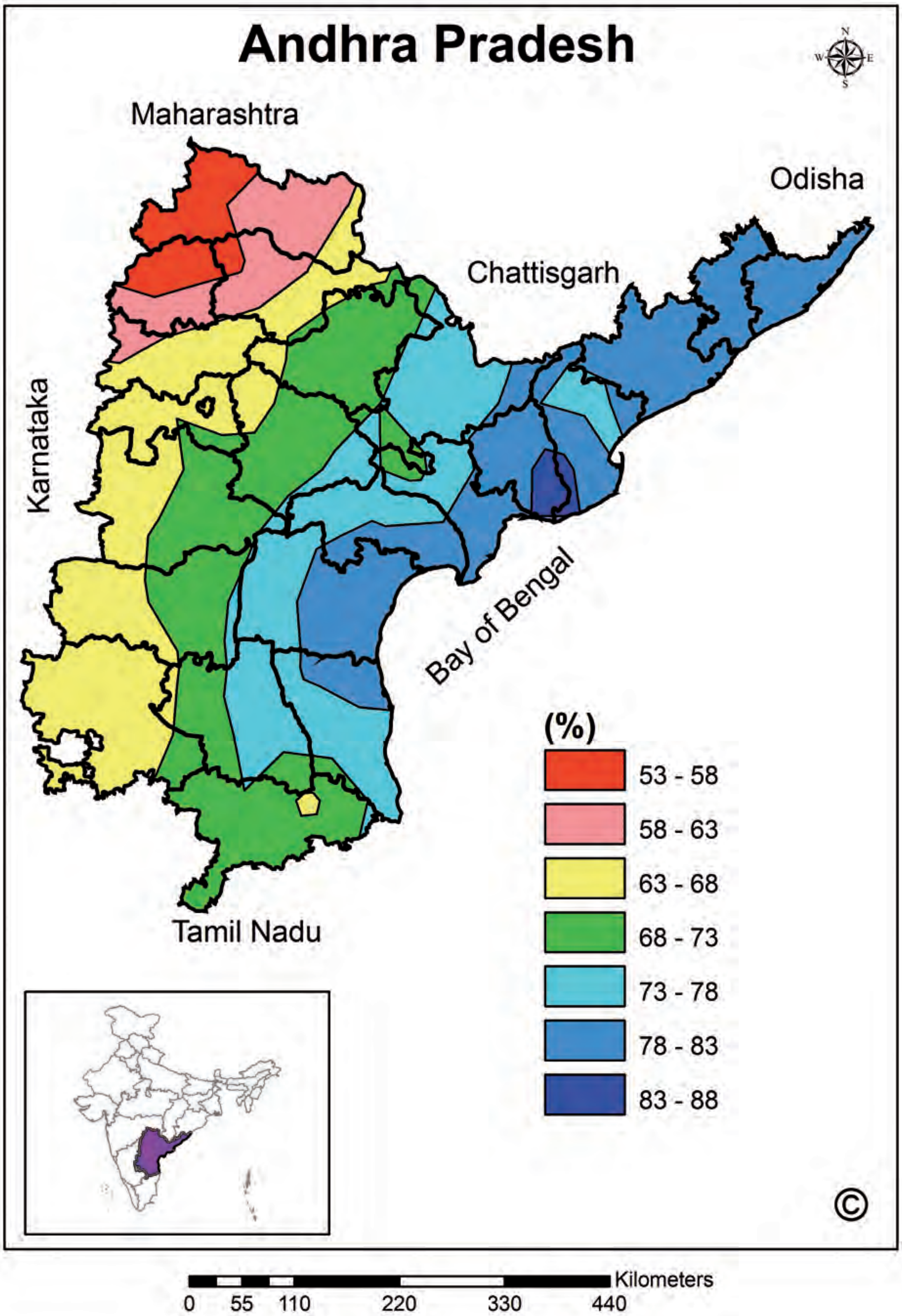


Fig. 109: Mean morning relative humidity during the summer season in Andhra Pradesh

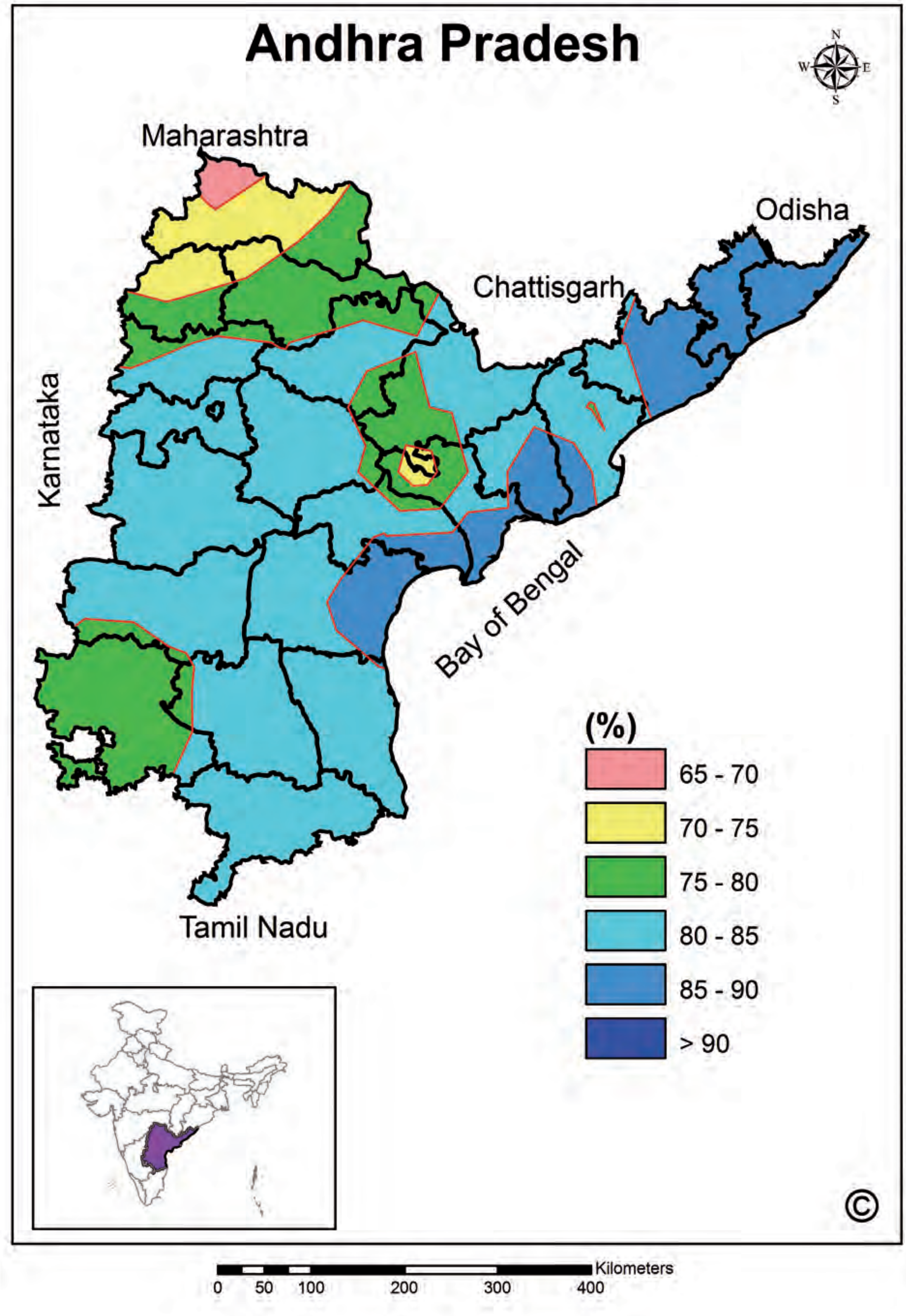


Fig. 110: Mean morning relative humidity during the winter season in Andhra Pradesh

6.2. Afternoon Relative Humidity over Andhra Pradesh

On an annual basis, relative humidity over Andhra Pradesh is 53% in the afternoon. Regional differences however exist in the Coastal regions. The RH is relatively high (61%), while over the other two region e.g. *Rayalaseema* it is 49%. Amongst the districts, Srikakulam has the afternoon RH of 72% followed by West Godavari (68%). These are the most humid areas. On the other hand, Anantapur (39%) and Nizamabad (42%) show much lower afternoon RH, so these are least humid (Fig. 111).

Mean monthly afternoon RH for the entire state (Table. 23) shows that August and September (64%) months are most humid and April (41%) is the least humid. When different regions are computed Coastal Andhra experiences high humid conditions over all the months. *Telangana* region is least humid during May (35%) and during the period from November to February compared to other regions. Amongst the districts, Nizamabad has an afternoon RH of 24% followed by Medak (27%). These two districts record least afternoon humidity in the month of May. Highest humidity during May is noted in the districts of Srikakulam (74%) followed by West Godavari (64%).

During the SWM period the mean afternoon RH of the entire state is 60%, while Coastal Andhra records the highest value of 66%. Least afternoon RH prevails over *Rayalaseema* (51%) (Fig. 112). Amongst the districts, Srikakulam has an afternoon RH of 79% followed by West Godavari (73%). These are most humid districts, whereas Anantapur (46%) followed by Chittoor (47%) are the least humid districts. The *Rayalaseema* region turns humid (60%) during NEM season. However, Coastal Andhra region continuous to be more humid with 64% afternoon humidity (Fig. 113). During the NEM season, Srikakulam district experience high afternoon humidity of (72%) followed by YSR Kadapa (71%). Driest districts during the NEM season are Nizamabad and Medak showing (44%) RH in the afternoon.

During summer lowest afternoon RH values are recorded as a mean for the entire state (42%). *Rayalaseema* and *Telangana* regions are on par (36%) with respect to the afternoon RH. During the summer season afternoon RH in the Coastal Andhra region averages (54%) (Fig. 114). In the Coastal districts, Srikakulam has RH of 69% followed by West Godavari (61%). These two districts tops the list. On the other hand, Nizamabad is the least humid with an afternoon RH of 23%. During winter season, afternoon RH is higher over *Rayalaseema* region (47%) compared to the *Telangana* region (45%). Coastal Andhra region nevertheless, experience high humidity of 57% in the afternoon. Winter season as a whole is more humid (49%) compared to summer (42%) in all the three regions (Fig. 115). West Godavari (66%) and Srikakulam (65%) districts in Coastal Andhra are the most humid during winter, whereas Nizamabad (32%) and Anantapur (33%) are the least humid districts as per records of afternoon RH.

Table 23: District average mean monthly afternoon relative humidity (%) over Andhra Pradesh

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	An-nual	Win-ter	Sum-mer	SWM	NEM
Anantapur	37	30	25	25	29	40	45	49	49	49	48	45	39	33	26	46	47
Chittor	49	40	32	33	35	40	46	50	53	61	64	59	47	45	33	47	61
YSR Kadapa	65	60	50	46	47	51	61	64	64	70	73	69	60	63	48	60	71
Average for Rayalaseema	**50**	**43**	**35**	**35**	**37**	**44**	**51**	**54**	**55**	**60**	**62**	**58**	**49**	**47**	**36**	**51**	**60**
Adilabad	61	56	47	40	42	50	72	73	70	67	68	69	60	59	43	66	68
Karimnagar	42	37	34	30	29	49	65	69	65	54	44	42	47	40	31	62	47
Khammam	49	46	48	46	42	50	63	70	66	65	59	52	55	48	45	62	59
Mahabubnagar	48	38	31	32	36	52	64	68	68	59	51	51	50	43	33	63	54
Medak	36	29	24	26	27	47	61	68	63	52	44	37	43	33	26	60	44
Nizamabad	35	29	23	23	24	46	63	67	63	53	43	37	42	32	23	60	44
Ranga Reddy	49	43	38	37	37	54	65	70	68	62	58	53	53	46	37	64	57
Warangal	60	58	51	48	43	55	67	71	69	66	63	60	59	59	47	66	63
Average for Telangana	**48**	**42**	**37**	**35**	**35**	**50**	**65**	**69**	**67**	**60**	**54**	**50**	**51**	**45**	**36**	**63**	**55**
East Godavari	57	54	53	54	48	54	68	73	73	68	60	55	60	56	52	67	61
Guntur	57	52	50	47	44	51	61	66	66	69	63	59	57	54	47	61	64
SPSR Nellore	60	55	52	54	53	53	60	65	64	68	67	64	60	57	53	60	66
Prakasam	63	58	54	52	47	52	59	60	61	68	70	66	59	61	51	58	68
Srikakulam	65	65	69	67	72	74	80	82	80	76	72	67	72	65	69	79	72
Visakhapatnam	49	47	48	52	56	59	66	67	68	64	54	48	56	48	52	65	55
Vizianagaram	49	43	42	50	50	56	61	66	66	66	47	44	53	46	47	62	52
West Godavari	68	64	64	60	59	64	76	77	76	75	69	67	68	66	61	73	70
Average for Coastal Andhra	**58**	**55**	**54**	**54**	**53**	**58**	**66**	**69**	**69**	**69**	**63**	**59**	**61**	**57**	**54**	**66**	**64**

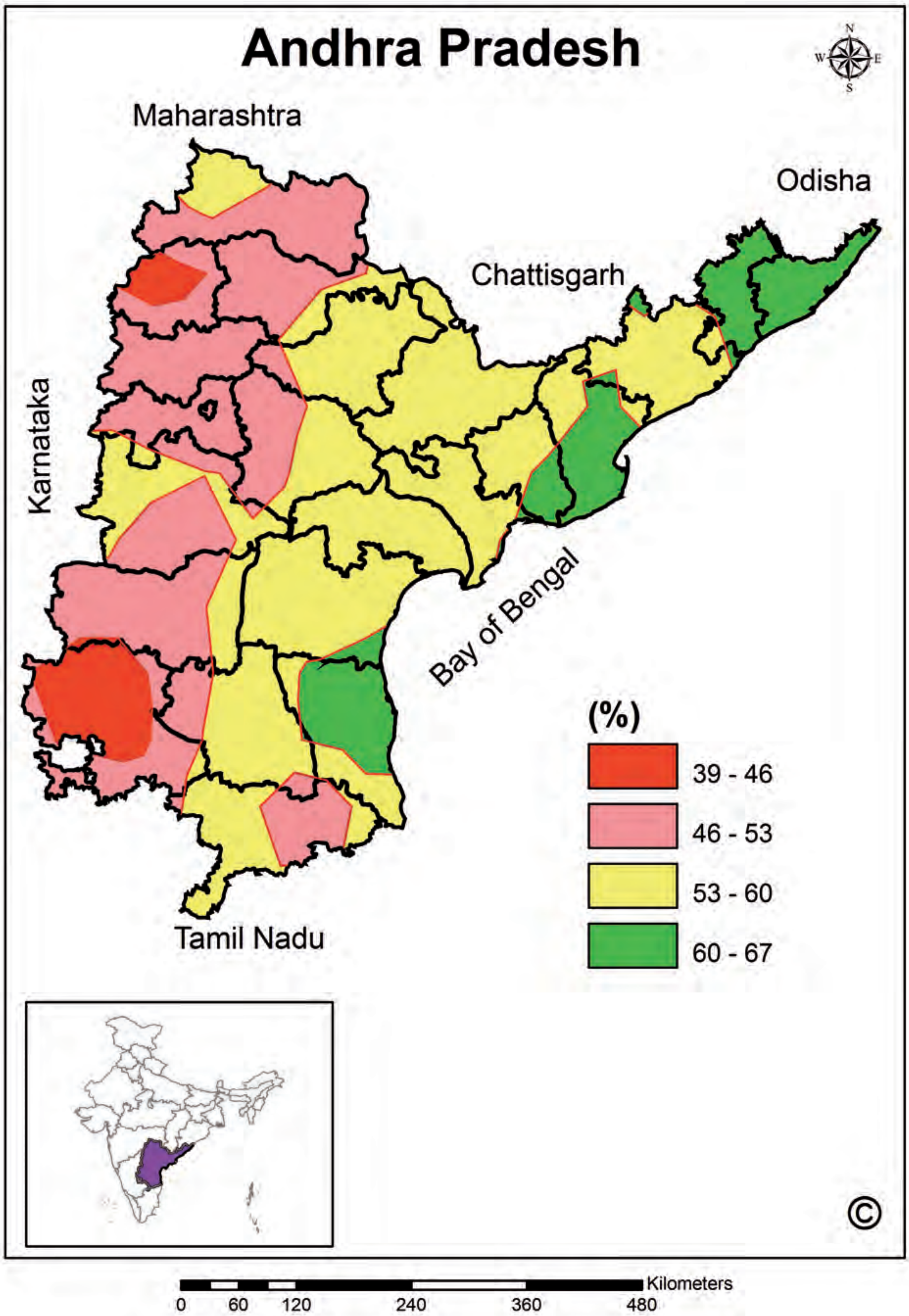


Fig. 111: Annual mean relative humidity (afternoon) over Andhra Pradesh

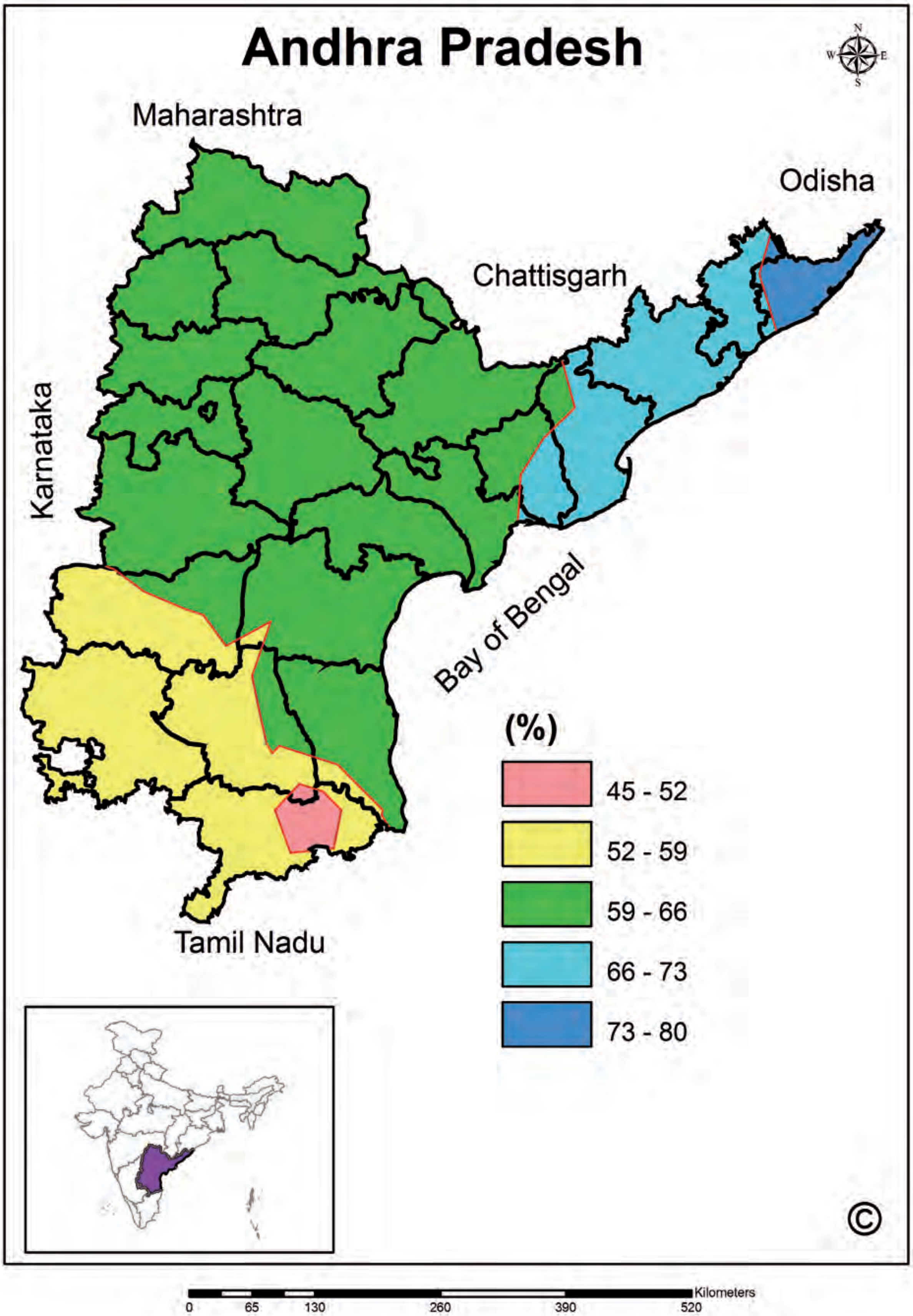


Fig. 112: Mean Southwest monsoon season relative humidity (afternoon) over Andhra Pradesh

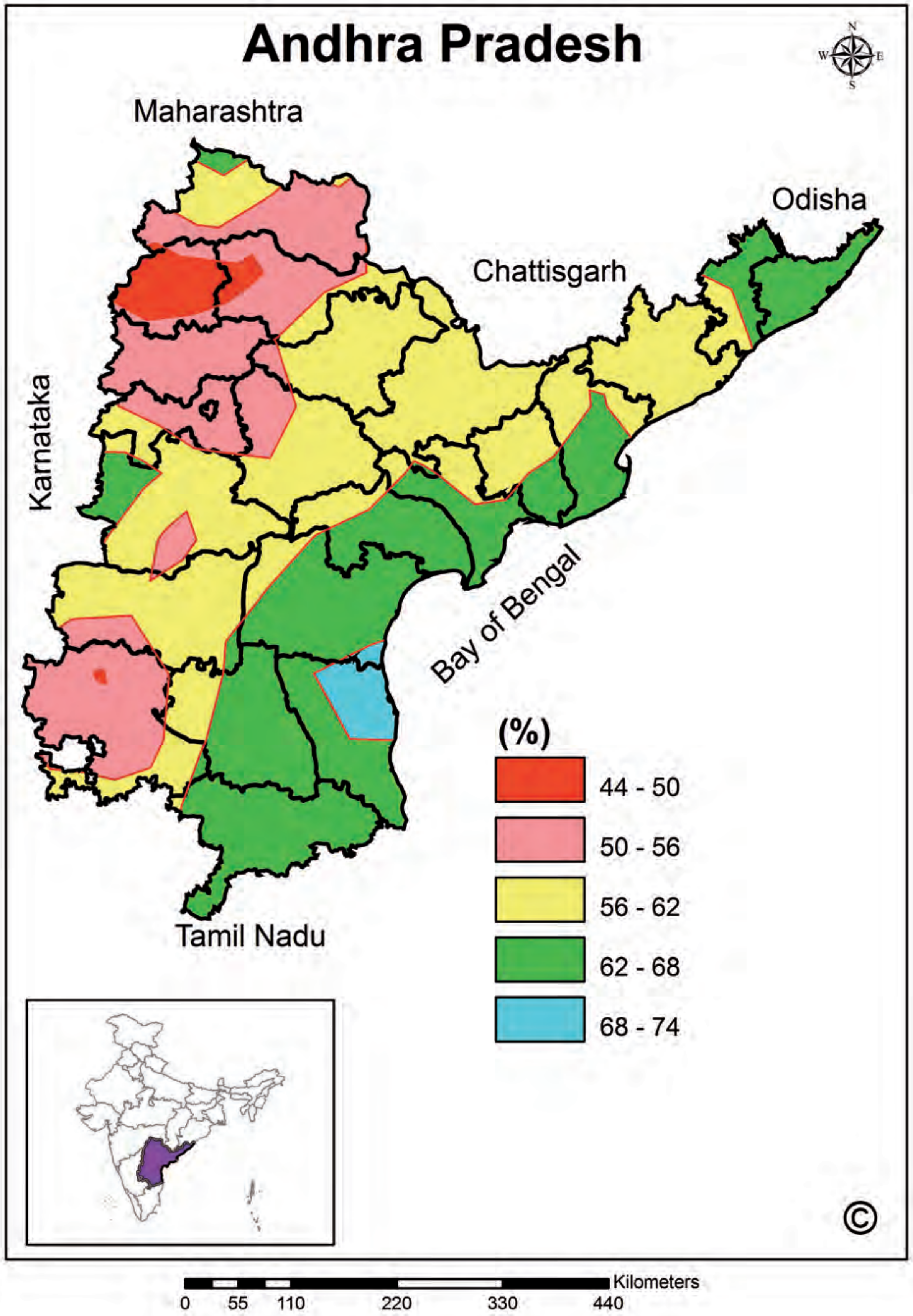


Fig. 113: Mean Northeast monsoon season relative humidity (afternoon) over Andhra Pradesh

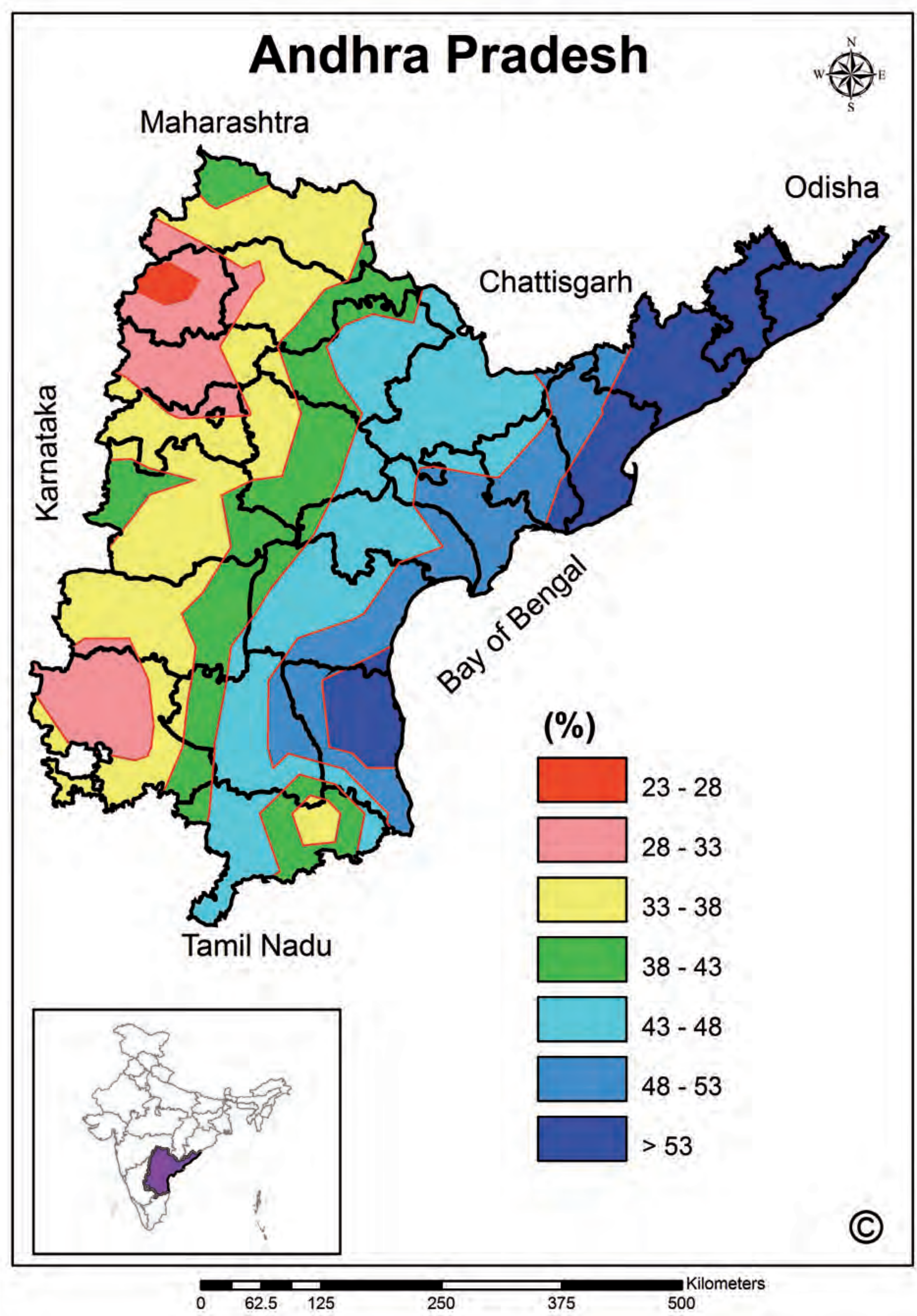


Fig. 114: Mean summer season relative humidity (afternoon) over Andhra Pradesh

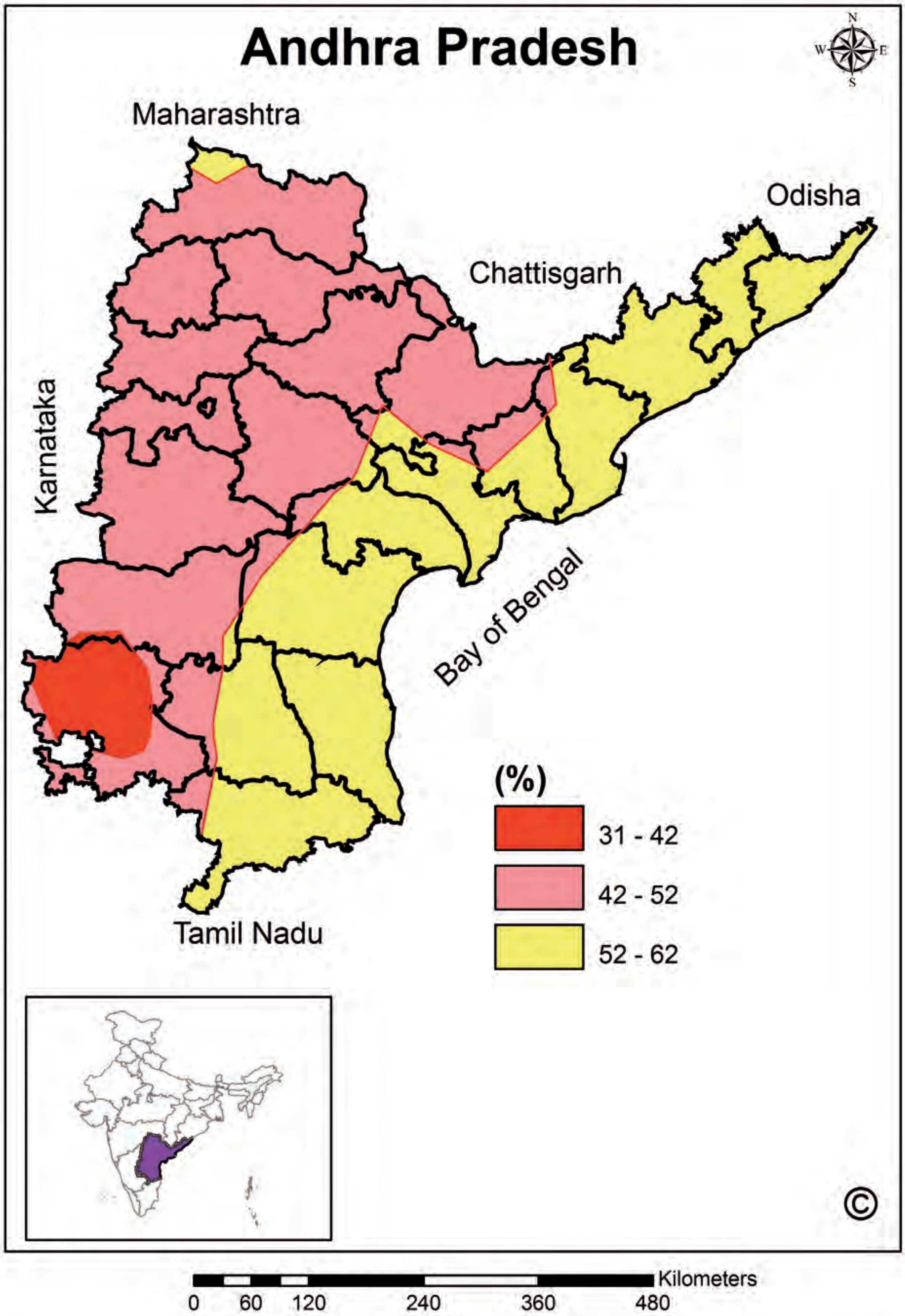


Fig. 115: Mean winter season relative humidity (afternoon) over Andhra Pradesh

7. Wind speed

The mean annual wind speed for the entire state is 6.7 kmph with *Telangana* region recording highest average wind speed of 7.0 kmph (Fig. 116). Coastal region is relatively calm with an average wind speed of 6.3 kmph. On an annual basis more windy conditions prevail over Hyderabad (16.1 kmph) and relatively calm conditions are observed in YSR Kadapa (3.6 kmph) and Visakhapatnam (3.7 kmph).

June is the month with high wind conditions for the entire state (10.2 kmph); and *Telangana* region during this month experiences high wind speeds (Table. 24). Hyderabad (24.7 kmph) and Anantapur (17.7 kmph) experience high winds during the month of June, whereas YSR Kadapa and Visakhapatnam districts experience relatively low windiness (4.4 kmph).

Wind speeds during SWM period range on an average between 7.7 to 9.3 kmph for the three different regions with a mean value of 8.7 kmph for the state (Fig. 117). Hyderabad district in *Telangana* (21.5 kmph) region and Anantapur in *Rayalaseema* region (15.8 kmph) are the two leading districts in windiness, whereas Visakhapatnam (3.7 kmph) district has calm conditions. Compared to SWM season, wind speed during NEM season are almost one half (4.6 kmph) (Fig. 118). Winds over *Telangana* regions are strong compared to other regions with Hyderabad district registering higher wind speeds (12.2 kmph). Prakasam and Khammam (2.3 kmph) districts experience low wind speeds.

Winds during summer season (7.1 kmph) are stronger than those during the NEM season for the state as a whole (Fig. 119). Strong winds prevail over the Coastal region during summer compared to other regions. Wind speeds over Hyderabad district are high (15.3 kmph) followed by Vizianagaram (13.8 kmph) and low wind speeds occur over YSR Kadapa district (3.7 kmph). During winter season also the winds are stronger than NEM season and Hyderabad experiences strong winds (12.6 kmph) followed by Vizianagaram (8.4 kmph) (Fig. 120). West Godavari and Karimnagar districts are the two relatively calm districts (2.8 kmph).

Table 24: District wise average mean monthly wind speed (kmph) in Andhra Pradesh

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	NEM
Anantapur	7.7	7.8	8.1	8.9	12.8	17.7	18.2	16.9	10.4	5.8	6.1	6.9	10.6	7.8	9.9	15.8	6.3
Chittor	6.2	6.2	6.1	6.2	9.7	11.4	11.2	10.0	7.0	5.2	5.6	5.9	7.6	6.2	7.3	9.9	5.6
YSR Kadapa	3.8	4.0	3.8	3.6	3.7	4.4	4.1	3.9	3.3	2.9	2.8	3.2	3.6	3.9	3.7	3.9	3.0
Kurnool	3.0	3.3	3.6	4.5	6.2	8.9	9.1	7.6	4.8	2.7	2.5	2.5	4.9	3.2	4.8	7.6	2.6
Average for Rayalaseema	**5.2**	**5.4**	**5.4**	**5.8**	**8.1**	**10.6**	**10.6**	**9.6**	**6.4**	**4.2**	**4.2**	**4.6**	**6.7**	**5.3**	**6.4**	**9.3**	**4.3**
Adilabad	2.8	3.4	3.8	4.6	5.9	6.8	6.8	6.5	5.2	3.5	3.2	2.8	4.6	3.1	4.8	6.3	3.2
Hyderabad	12.0	13.2	13.3	14.3	18.2	24.7	23.2	21.8	16.2	12.3	12.7	11.6	16.1	12.6	15.3	21.5	12.2
Karimnagar	2.4	3.2	3.8	4.2	6.8	9.5	8.1	7.3	4.6	4.5	2.5	2.1	4.9	2.8	4.9	7.4	3.1
Khammam	2.7	3.7	4.5	5.5	5.0	4.6	4.2	4.2	2.9	2.5	2.2	2.1	3.7	3.2	5.0	4.0	2.3
Mahabubnagar	4.5	4.5	4.9	6.0	7.5	10.1	10.0	8.7	5.8	4.7	5.0	4.9	6.4	4.5	6.1	8.7	4.8
Medak	6.9	7.6	7.9	8.7	11.3	16.2	14.8	11.6	7.4	5.6	6.1	5.7	9.2	7.3	9.3	12.5	5.8
Nizamabad	3.7	4.4	4.9	5.2	6.4	8.2	7.9	7.2	5.3	3.7	3.8	3.3	5.3	4.1	5.5	7.1	3.6
Ranga Reddy	4.4	5.1	5.5	5.9	8.3	12.6	12.8	10.9	6.4	4.0	4.1	3.6	7.0	4.7	6.6	10.7	3.9
Warangal	6.8	8.2	7.9	7.9	7.6	4.7	2.6	3.9	5.0	6.3	7.4	6.4	6.2	7.5	7.8	4.0	6.7
Average for Telangana	**5.1**	**5.9**	**6.3**	**6.9**	**8.6**	**10.8**	**10.0**	**9.1**	**6.5**	**5.2**	**5.2**	**4.7**	**7.0**	**5.5**	**7.3**	**9.1**	**5.1**
East Godavari	3.9	4.2	5.2	6.8	7.5	9.3	8.9	8.3	6.0	5.0	5.4	4.5	6.2	4.1	6.5	8.1	5.0
Guntur	4.4	6.3	7.7	9.6	10.4	11.0	9.1	8.3	5.5	4.3	4.0	3.5	7.0	5.4	9.2	8.5	3.9
SPSR Nellore	5.7	6.8	8.4	9.3	9.0	9.8	8.5	8.6	7.3	5.8	6.2	6.1	7.6	6.2	8.9	8.6	6.0
Prakasam	2.6	3.3	4.2	4.6	7.2	10.4	10.9	10.1	4.8	3.1	1.5	2.5	5.4	3.0	5.3	9.1	2.3
Srikakulam	3.0	3.7	5.5	8.4	8.5	7.3	5.2	4.7	3.3	3.0	2.5	2.6	4.8	3.4	7.5	5.1	2.7
Visakhapatnam	3.0	3.5	4.2	5.2	4.8	4.4	3.9	3.4	2.9	2.8	2.9	3.0	3.7	3.2	4.8	3.7	2.9
Vizianagaram	7.9	9.0	11.5	15.3	14.6	13.1	12.4	11.1	8.5	6.9	9.5	8.3	10.7	8.4	13.8	11.3	8.2
West Godavari	3.2	2.4	2.2	4.0	5.7	8.0	9.6	8.3	4.6	3.3	3.6	3.9	4.9	2.8	4.0	7.6	3.6
Average for Coastal Andhra	**4.2**	**4.9**	**6.1**	**7.9**	**8.5**	**9.2**	**8.6**	**7.8**	**5.4**	**4.3**	**4.5**	**4.3**	**6.3**	**4.6**	**7.5**	**7.7**	**4.3**

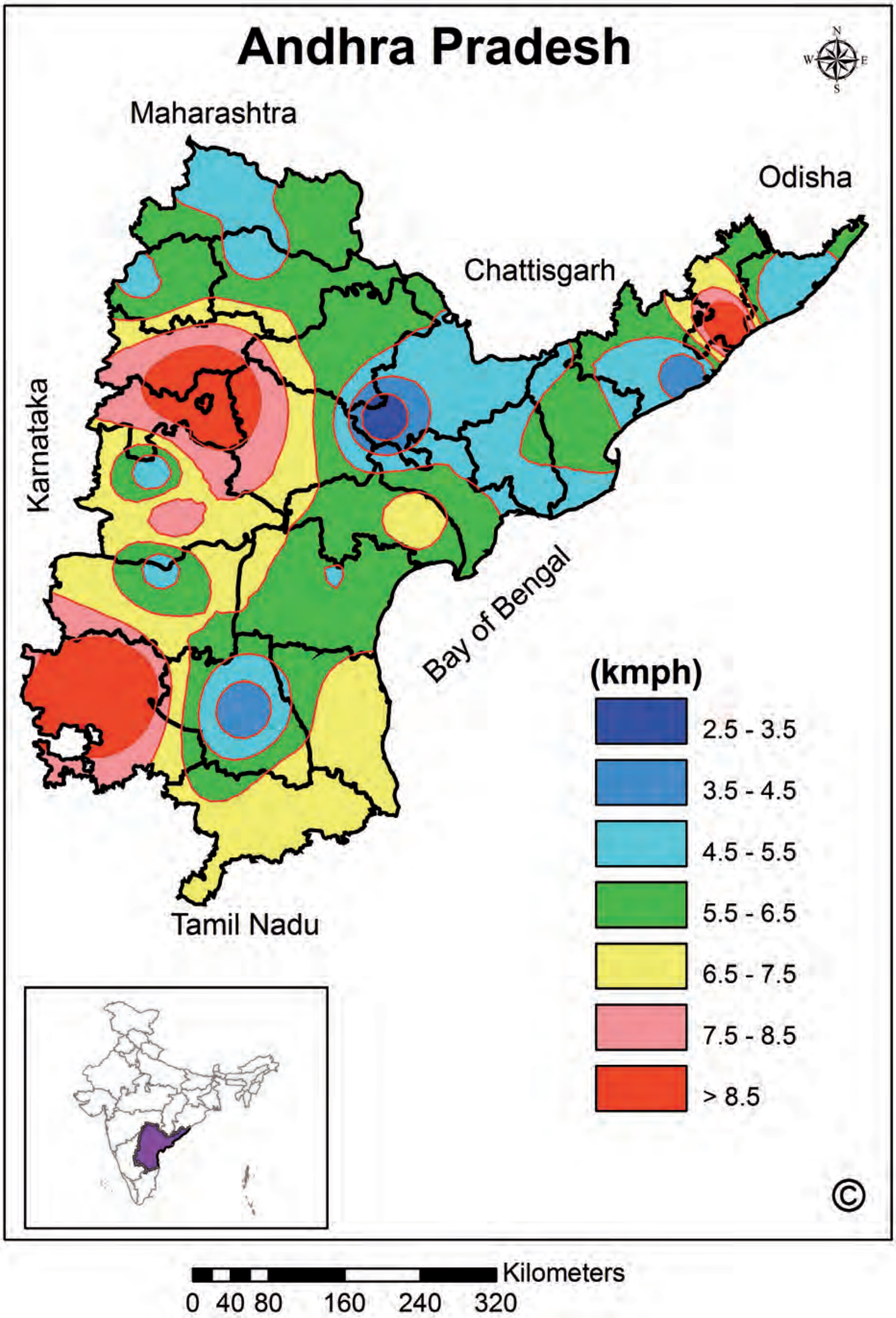


Fig. 116: Annual mean wind speeds over Andhra Pradesh

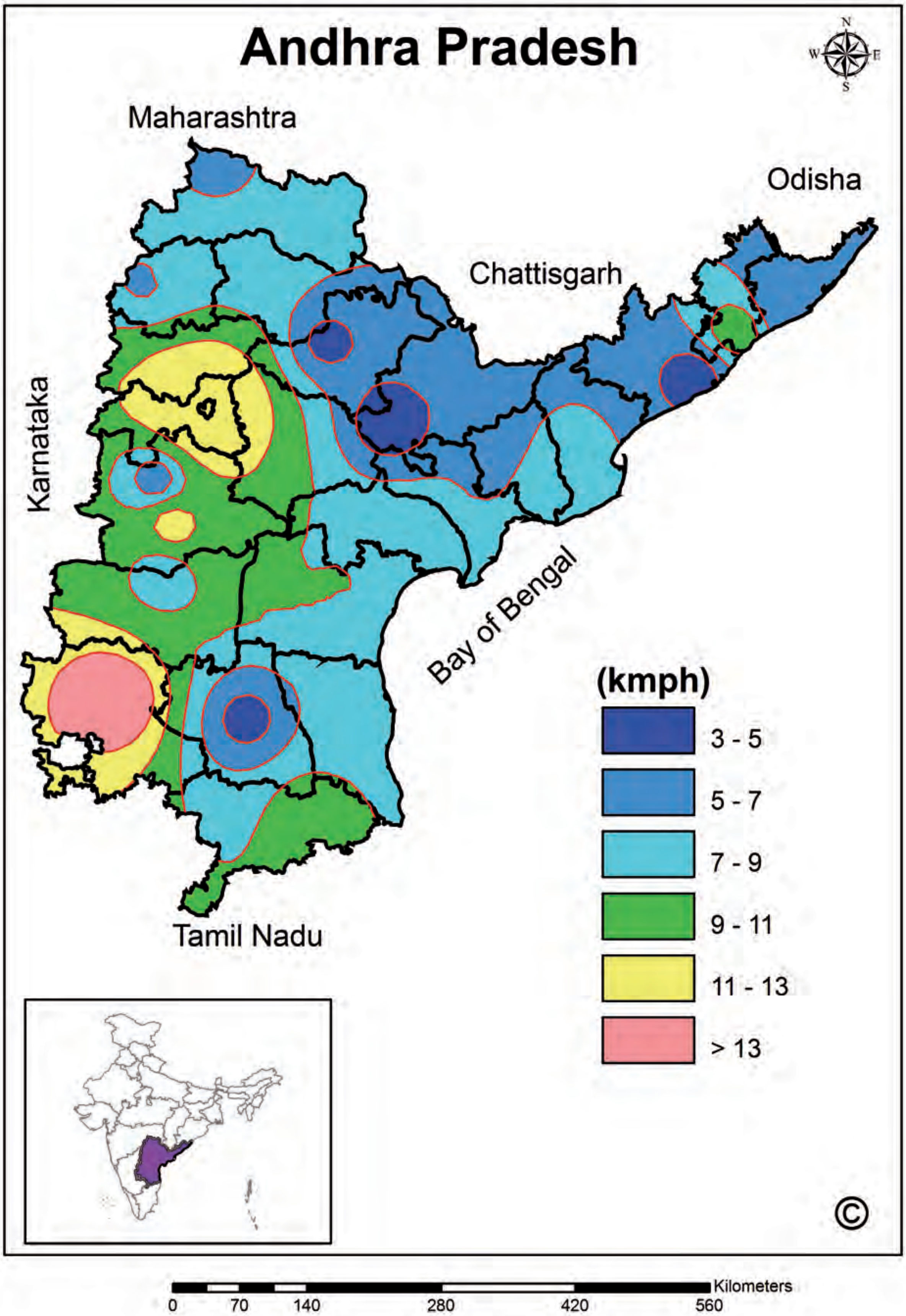


Fig. 117: Southwest monsoon season mean wind speeds over Andhra Pradesh

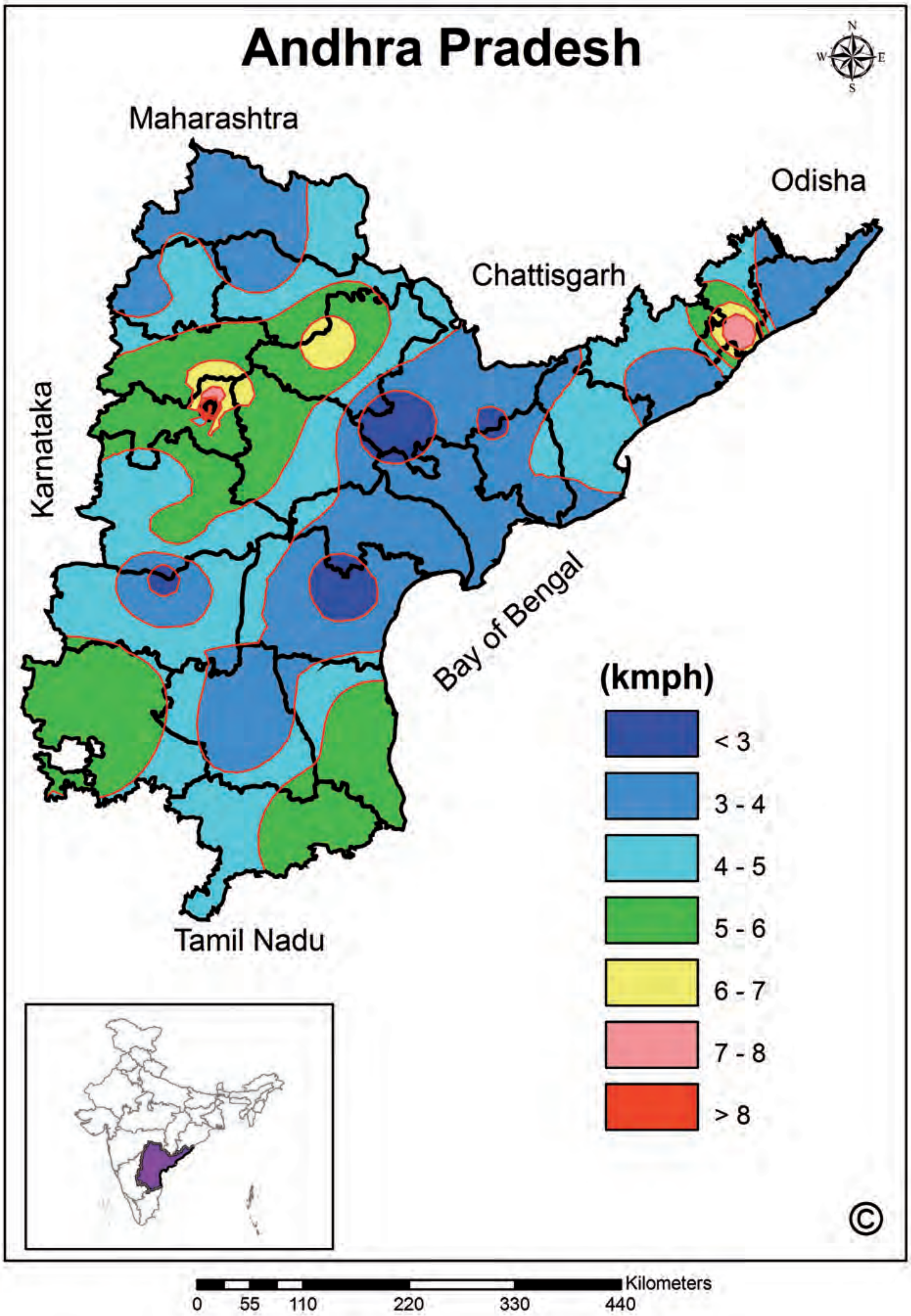


Fig. 118: Northeast monsoon season mean wind speeds over Andhra Pradesh

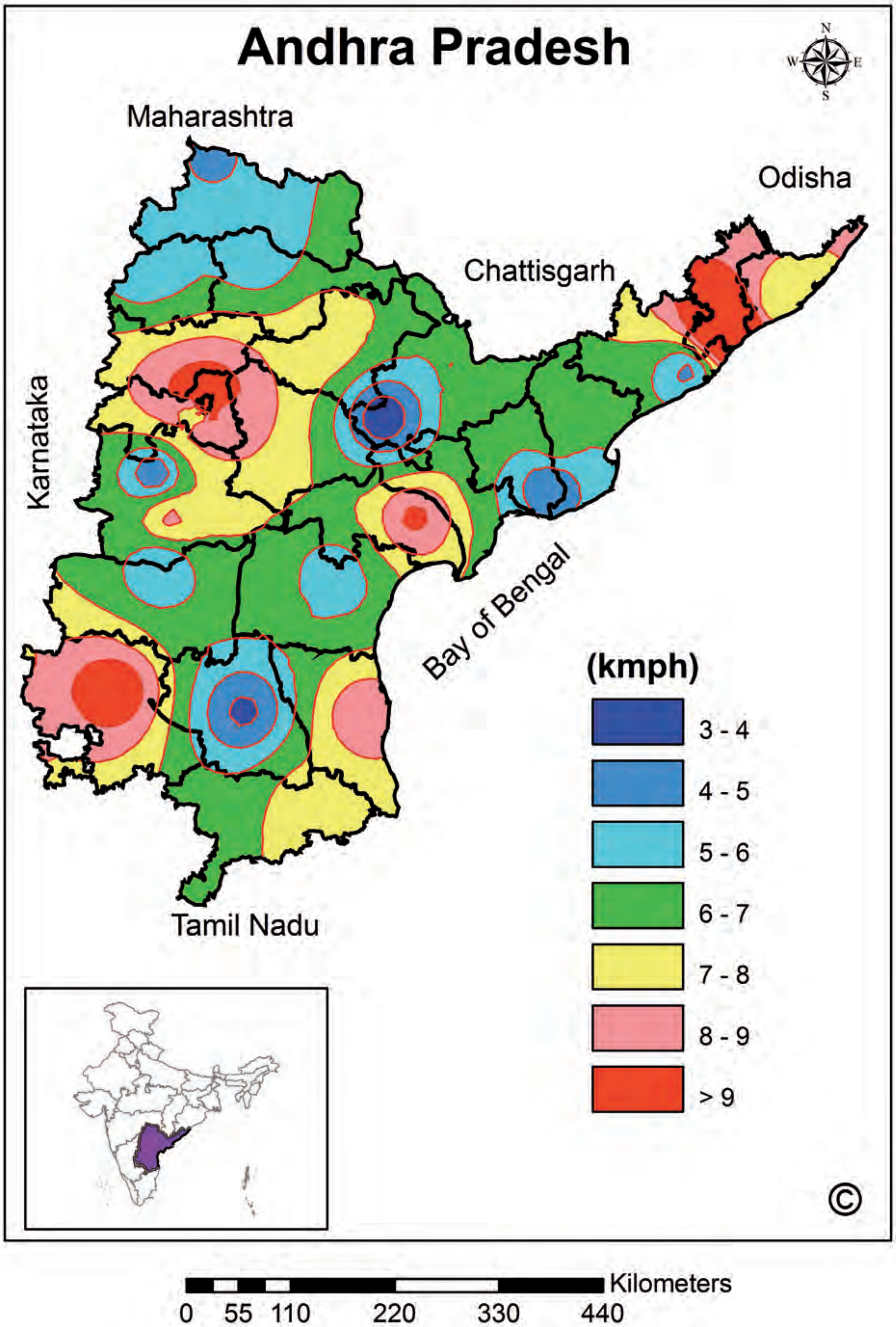


Fig. 119: Summer season mean wind speeds over Andhra Pradesh

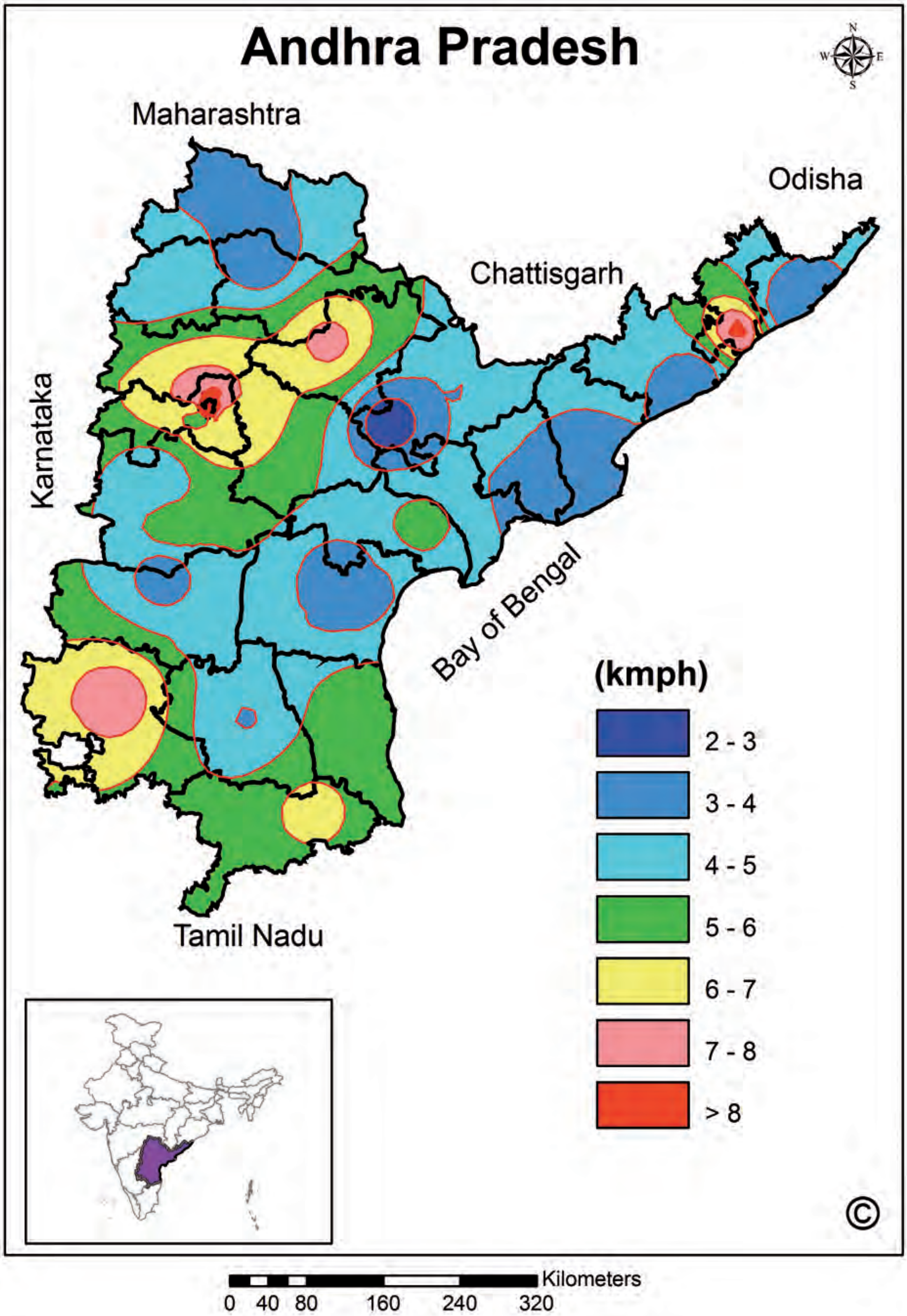


Fig. 120: Winter season mean wind speeds over Andhra Pradesh

8. Sunshine hours

Mean annual number of hours of bright sunshine for the state are 7 hrs/day with *Telangana* (7.3 hrs/day) receiving sunlight for a longer period (Fig. 121). Anantapur (8.1 hrs/day) is the brightest district and Srikakulam (5.7 hrs/day) is the dimmest. February month is the month with longest days (9 hrs/day) and July is the month of days with shorter day length (4.4 hrs/day) (Table. 25). Anantapur district receives day light for the longest period (10.2 hrs/day) and this occurs in the month of March. Ranga Reddy district follows Anantapur with a mean monthly value of 10 hrs/day. Srikakulam district receives sunlight for the shortest period of 2.8 hrs/day in the month of July.

Of all the four seasons SWM season receives sun light for the shortest period (5.1 hrs/day). The Coastal Andhra region records the lowest number of hours/day of bright sunlight (4.9 hrs) in the three regions (Fig. 122). Prakasam district records 6.8 hrs/day followed by Anantapur district (6.2 hrs/day) sunshine for longer duration during SWM season and Srikakulam (3.7 hrs/day) the least. Compared to SWM season, the hours of sunshine during a day are high (6.8 hrs/day) during NEM season for the state as a whole (Fig. 123). *Telangana* region receives on an average sunlight for 7.6 hrs/day, which is far above the other two regions. SPSR Nellore (8.3 hrs/day) and Medak (8.2 hrs/day) districts receive bright sunlight for a longer period, and Chittoor district for the shortest period (4.2 hrs/day) during the NEM season.

Summer and winter seasons experience similar day length (8.6 hrs/day) on the state as a whole, but summers have longer day length over *Rayalaseema* (9.1 hrs/day) compared to the Coastal region (7.8 hrs/day) (Fig. 124). Anantapur (9.9 hrs/day) followed by Prakasam (9.6 hrs/day) have longer days during summer, whereas Srikakulam (6.2 hrs/day) and SPSR Nellore (6.3 hrs/day) experience shorter days. During winter season also *Rayalaseema* experiences longer days (9.0 hrs/day) compared to the Coastal region (8.0 hrs/day) (Fig. 125). Anantapur (9.8 hrs/day) followed by Medak (9.4 hrs/day) districts have longer day light hours. Srikakulam (7.1 hrs/day) and West Godavari (7.2 hrs/day), on the other hand, experience day length for short periods.

Table 25: District annual, monthly and seasonal mean sunshine hours/day

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	NEM
Anantapur	9.5	10.1	10.2	10.1	9.5	7.0	5.5	5.5	6.9	7.3	7.7	8.2	8.1	9.8	9.9	6.2	7.7
Chittoor	7.6	8.7	8.9	8.9	7.0	4.6	3.5	4.1	5.1	3.1	4.2	5.3	5.9	8.2	8.3	4.3	4.2
Average for Rayalaseema	**8.6**	**9.4**	**9.6**	**9.5**	**8.2**	**5.8**	**4.5**	**4.8**	**6.0**	**5.2**	**6.0**	**6.7**	**7.0**	**9.0**	**9.1**	**5.3**	**6.0**
Karimnagar	7.7	8.5	8.0	8.8	8.1	5.4	3.3	3.7	5.7	7.1	7.4	7.2	6.7	8.1	8.3	4.5	7.2
Khammam	8.8	9.5	9.6	9.6	9.3	7.1	5.4	4.8	7.0	7.1	7.8	8.6	7.9	9.1	9.5	6.1	7.8
Mahabubnagar	8.6	9.4	8.6	8.5	8.3	5.0	4.4	3.7	5.0	6.1	6.8	7.3	6.8	9.0	8.5	4.5	6.7
Medak	9.2	9.7	9.4	9.4	9.1	6.0	4.1	4.2	5.8	7.4	8.2	8.8	7.6	9.4	9.3	5.0	8.2
Ranga Reddy	8.7	9.4	10.0	8.9	8.7	5.9	4.3	4.4	5.6	7.2	8.0	8.4	7.4	9.1	9.2	5.0	7.8
Average for Telangana	**8.6**	**9.3**	**9.1**	**9.0**	**8.7**	**5.9**	**4.3**	**4.2**	**5.8**	**7.0**	**7.6**	**8.1**	**7.3**	**8.9**	**9.0**	**5.0**	**7.6**
East Godavari	8.2	8.8	8.5	8.6	8.3	4.9	3.8	4.0	4.9	5.9	7.2	7.7	6.7	8.5	8.4	4.4	6.9
Guntur	7.1	8.3	8.2	8.8	8.2	5.8	4.8	4.3	5.0	5.5	6.5	6.5	6.6	7.7	8.4	5.0	6.2
SPSR Nellore	9.1	8.6	7.1	5.8	5.8	6.0	6.0	6.0	6.4	7.5	8.8	8.7	7.2	8.9	6.3	6.1	8.3
Prakasam	8.5	9.6	9.5	9.8	9.4	7.0	5.8	6.9	7.3	6.8	6.3	7.3	7.9	9.0	9.6	6.8	6.8
Srikakulam	7.1	7.1	6.4	7.0	5.2	3.4	2.8	4.4	4.1	6.5	8.9	6.2	5.7	7.1	6.2	3.7	7.2
Visakhapatnam	7.2	7.7	8.0	8.3	7.3	4.7	4.2	4.0	4.9	6.0	7.1	7.3	6.4	7.5	7.9	4.5	6.8
West Godavari	6.8	7.6	8.0	8.6	7.3	4.4	3.8	3.9	4.5	5.3	6.2	6.2	6.1	7.2	8.0	4.2	5.9
Average for Coastal Andhra	**7.7**	**8.2**	**8.0**	**8.1**	**7.4**	**5.2**	**4.5**	**4.8**	**5.3**	**6.2**	**7.3**	**7.1**	**6.6**	**8.0**	**7.8**	**4.9**	**6.9**

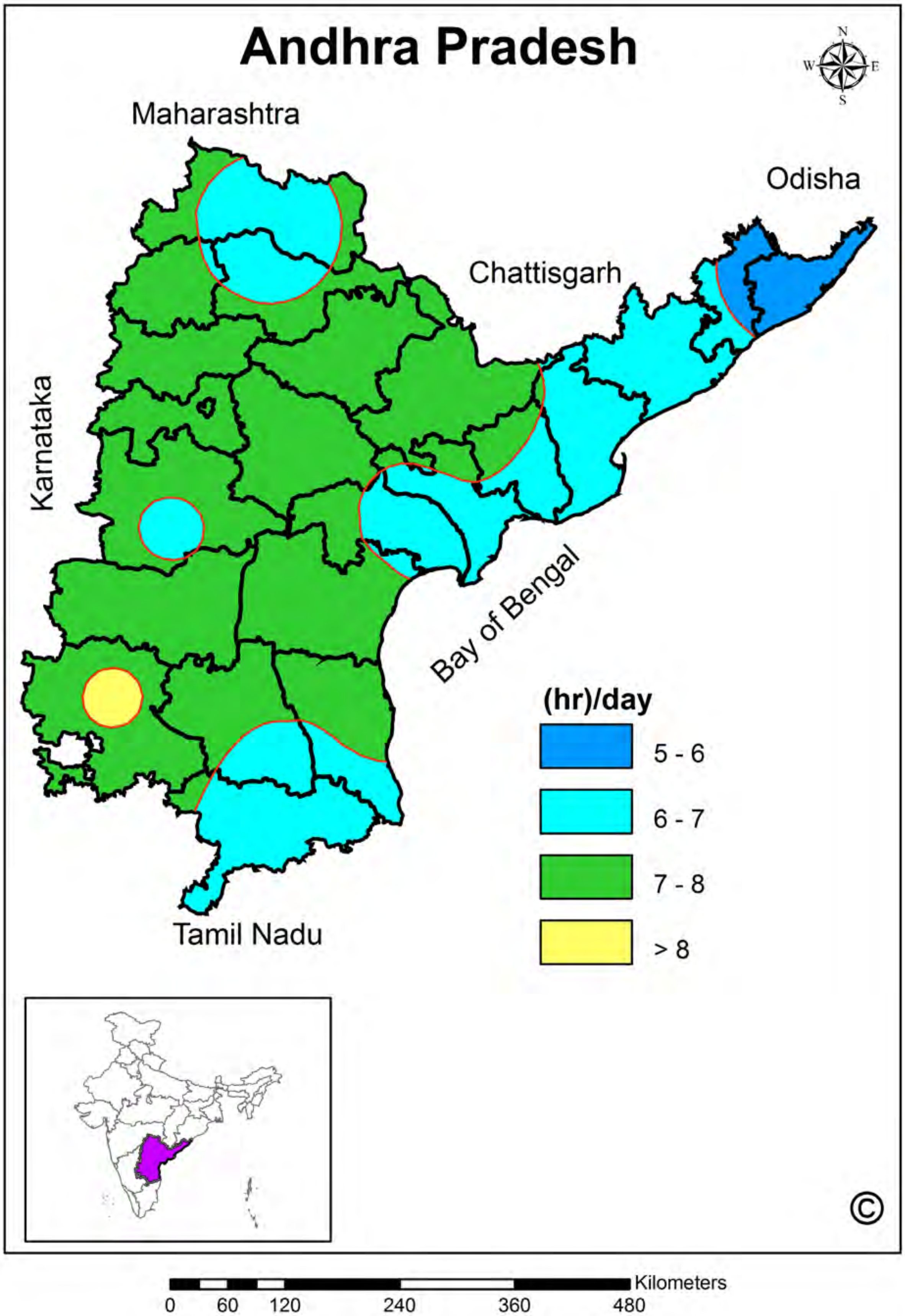


Fig. 121: Annual mean sunshine hours over Andhra Pradesh

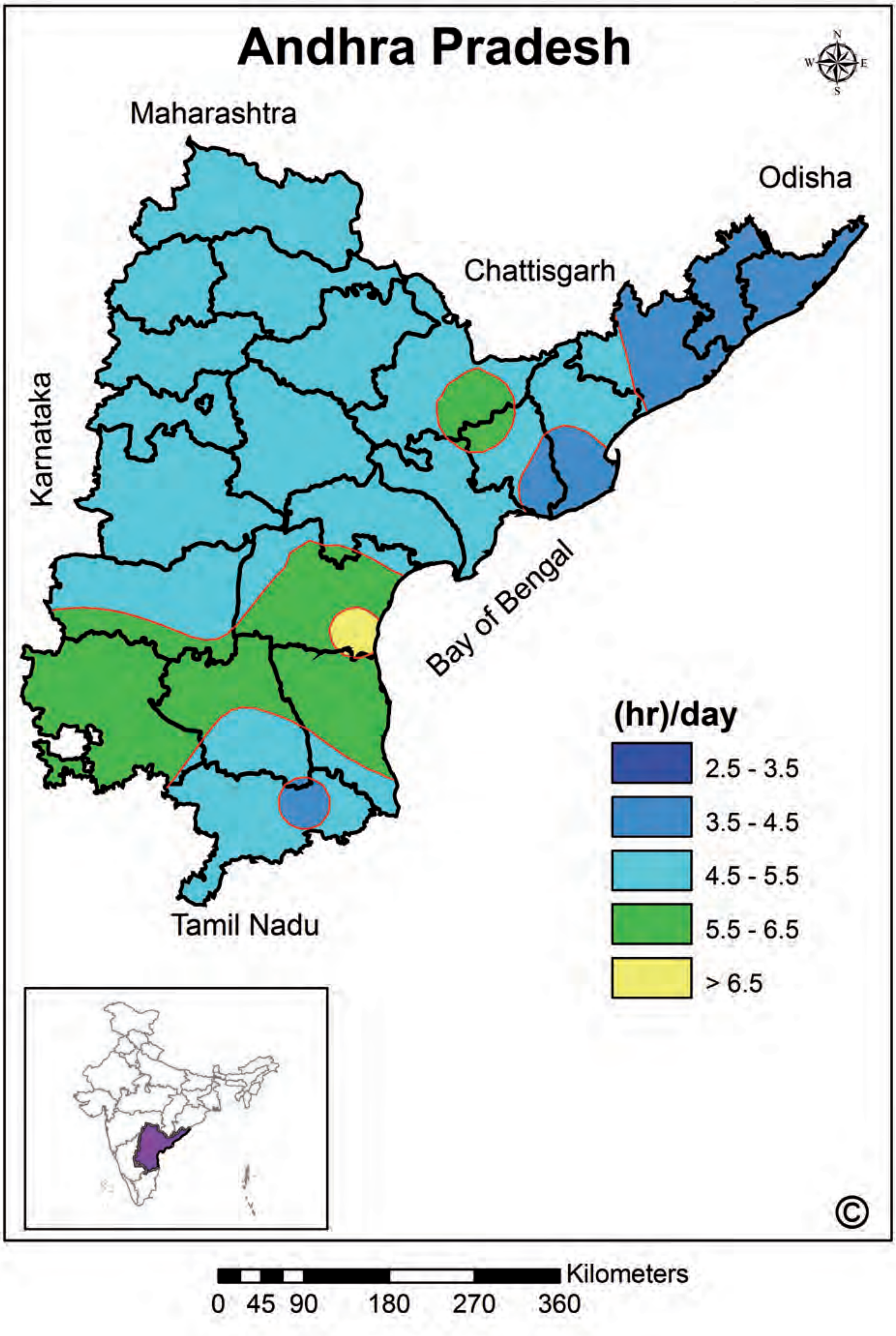


Fig. 122: Southwest monsoon season mean sunshine hours/day over Andhra Pradesh

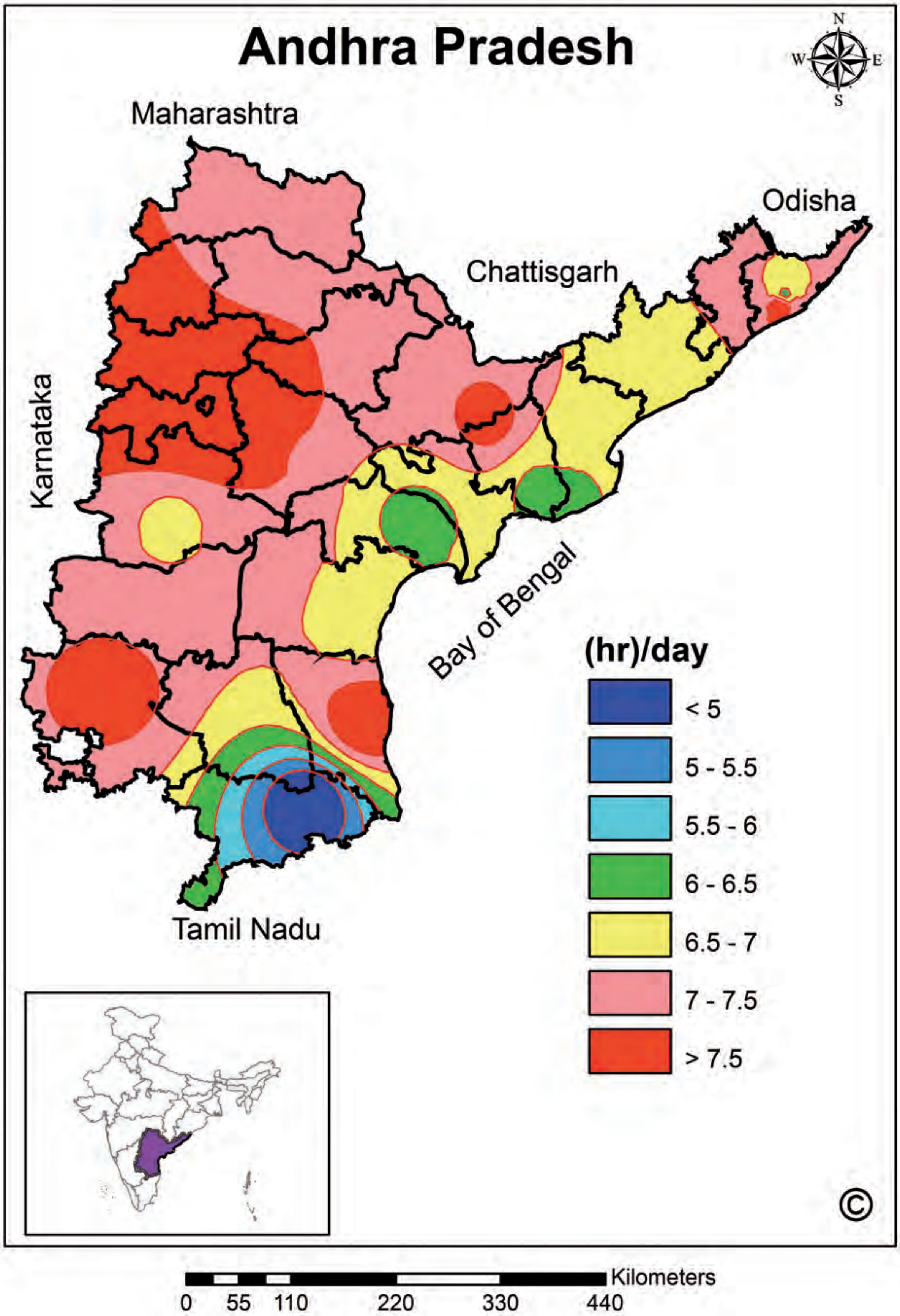


Fig. 123: Northeast monsoon season mean sunshine hours/day over Andhra Pradesh

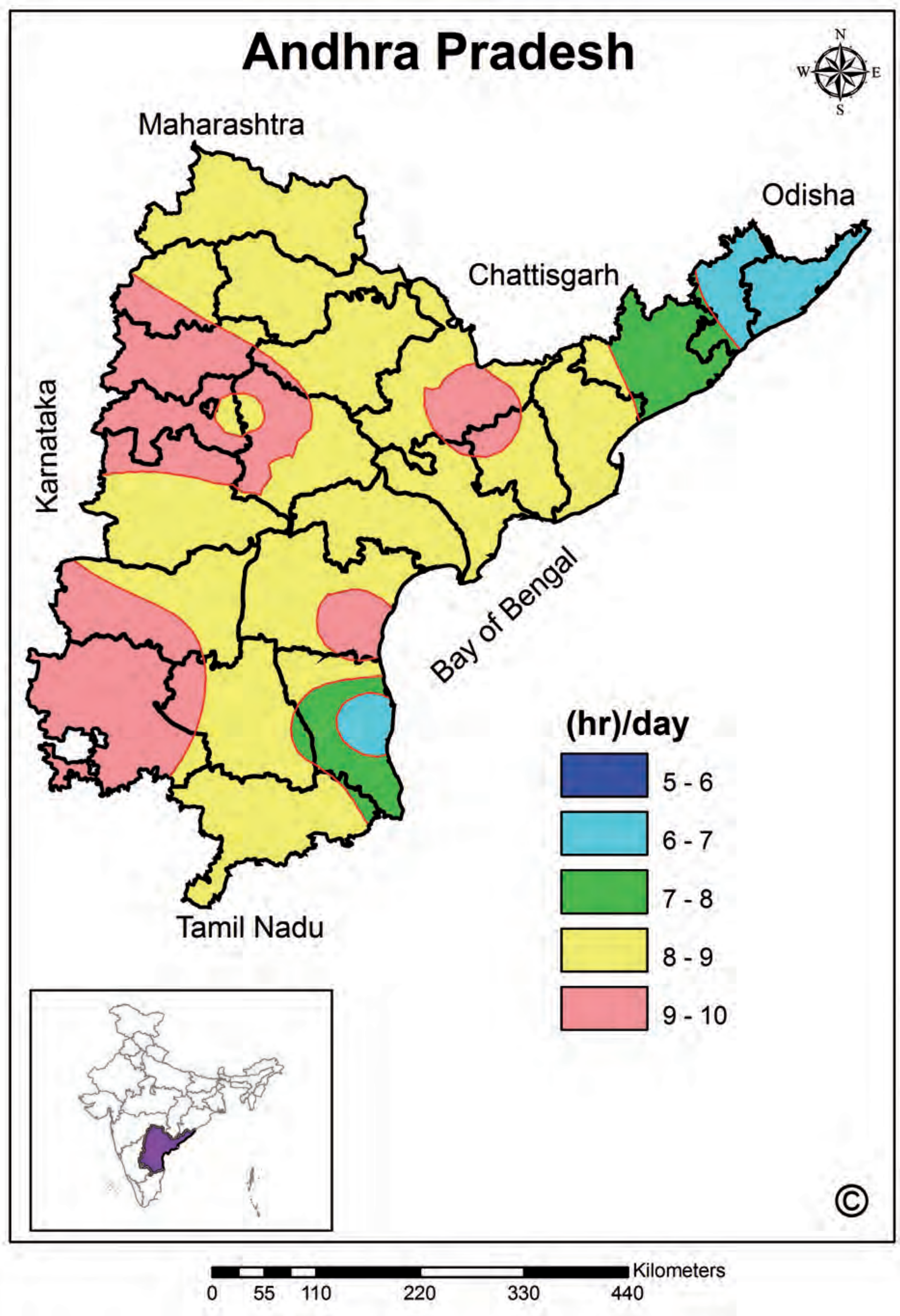


Fig. 124: Summer season mean sunshine hours/day over Andhra Pradesh

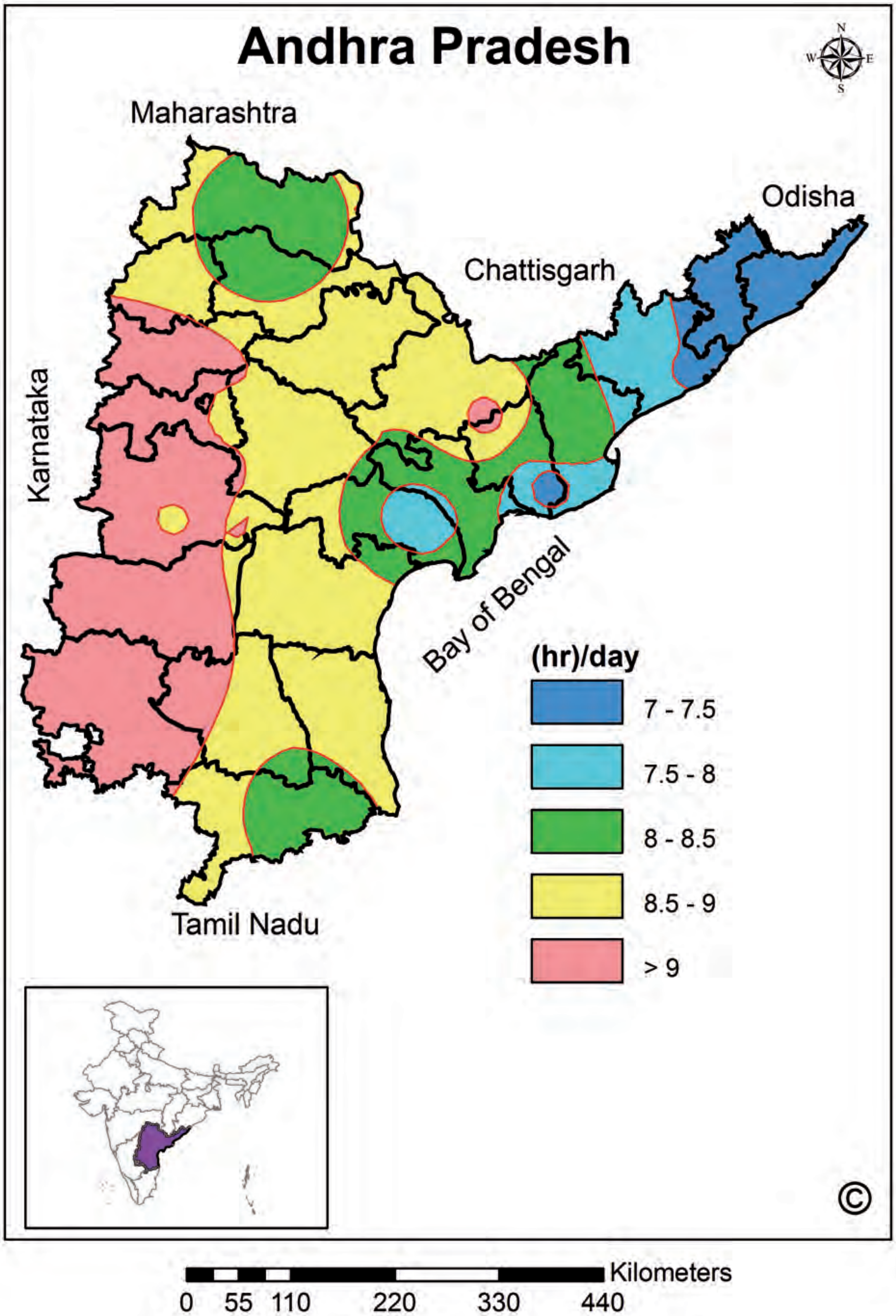


Fig. 125: Winter season mean sunshine hours /day over Andhra Pradesh

9. Open-pan evaporation (E_0)

The USWB class A Open-pan evaporimeter (mesh covered) was used to collect data from selected locations; its analysis showed that the average total annual evaporation of the state is 1945 mm. Evaporation in the *Rayalaseema* region is the highest (2357 mm) and is lowest over Coastal region (1634 mm) (Fig. 126). Amongst the districts Anantapur ranked first with an annual evaporation value of 2674 mm followed by Medak (2390 mm). Least evaporation is recorded in Warangal (1255 mm) followed by Srikakulam (1313 mm).

May is the month of maximum evaporation; the total evaporation for May is 251 mm for the entire state closely followed by April (220 mm). During May amount of highest evaporation is recorded in Medak (363 mm) followed by Karimangar district (327 mm) (Table. 26). The least evaporation during this month has been observed in Warangal (146 mm) district.

The seasonal total evaporation during SWM, for the state as a whole is 650 mm with *Rayalaseema* region registering 823 mm seasonal evaporation (Fig. 127). Evaporation during this SWM season is least over *Telangana* region (557 mm). Amongst the districts, Anantapur experiences high evaporative conditions during SWM season with a total E_0 value of 895 mm followed by SPSR Nellore (758 mm) district. Least evaporation occurs during this season in Warangal (338 mm), followed by Srikakulam (381 mm) district. During NEM season the total seasonal evaporation for the entire state is 345 mm with *Rayalaseema* registering a peak value of 414 mm and Coastal region with the least value of 283 mm (Fig. 128). Amongst the districts, once again, Anantapur tops the list with 518 mm of seasonal E_0 followed by Medak district (410 mm). During this season Prakasam district experiences lowest evaporative demand with a total seasonal evaporation value of 157 mm closely followed by Nalgonda (262 mm).

A comparison of four season, summer season records highest evaporation (670 mm); *Rayalaseema* region on average experience a total evaporation of 750 mm; and Coastal region records a value of 564 mm (Fig. 129). During the summer season Medak district experience the highest evaporative demand with a seasonal total of 936 mm followed by Anantapur district (825 mm). Prakasam (557 mm) and SPSR Nellore (587 mm) are the two districts that experience low evaporation during summer. Winter is the season during which least evaporation occurs (279 mm for state) and the *Rayalaseema* region tops with a seasonal total value of 370 mm (Fig. 130). Anantapur district once again tops in winter season evaporation with a value of 436 mm closely followed by Medak (337 mm). Least evaporation during winter season occurs over Warangal (163 mm) and West Godavari (169 mm) districts.

Table 26: Monthly open-pan evaporation (mm) for some districts of *Rayalaseema*, *Telangana* and Coastal Andhra Pradesh

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	An-nual	Winter	Sum-mer	SWM	NEM
Anantapur	206	231	262	279	284	230	238	230	198	188	163	167	2674	436	825	895	518
Chittor	142	162	213	214	249	215	202	187	146	110	94	106	2040	304	676	751	310
Average for Rayalaseema	**174**	**196**	**238**	**247**	**266**	**223**	**220**	**209**	**172**	**149**	**129**	**137**	**2357**	**370**	**750**	**823**	**414**
Karimnagar	112	135	196	246	327	248	143	124	123	124	108	102	1985	247	768	637	333
Khammam	93	136	184	224	258	185	123	119	131	113	122	106	1793	229	666	558	341
Mahabubnagar	127	162	230	251	309	236	184	147	128	117	116	120	2126	289	790	694	353
Medak	150	187	270	303	363	262	179	136	131	141	135	134	2390	337	936	707	410
Nalgonda	85	116	172	206	238	179	130	104	106	95	86	82	1598	201	615	520	262
Nizamabad	119	150	199	244	287	151	98	93	106	115	119	121	1801	268	731	448	355
Ranga Reddy	117	145	197	218	263	192	139	115	108	113	105	105	1817	262	678	554	324
Warangal	77	86	116	124	146	102	61	88	86	195	90	83	1255	163	387	338	368
Average for Telangana	**110**	**140**	**195**	**227**	**274**	**194**	**132**	**116**	**115**	**127**	**110**	**107**	**1846**	**250**	**696**	**557**	**343**
SPSR Nellore	101	118	160	192	236	225	194	172	167	119	90	91	1863	218	587	758	300
Prakasam	75	101	158	176	223	182	147	118	108	68	44	45	1444	176	557	554	157
Srikakulam	88	104	147	169	155	119	79	92	91	109	80	81	1313	192	471	381	269
Visakhapatnam	103	127	170	185	195	152	130	114	105	98	106	98	1584	230	550	502	302
West Godavari	83	87	110	142	171	165	136	110	106	87	82	81	1359	169	423	517	250
East Godavari	130	143	187	204	228	188	125	115	110	119	126	128	1802	273	619	537	373
Guntur	114	145	206	243	288	246	189	170	140	127	94	107	2069	259	738	744	329
Average for Coastal Andhra	**99**	**118**	**163**	**187**	**214**	**183**	**143**	**127**	**118**	**104**	**89**	**90**	**1634**	**217**	**564**	**571**	**283**

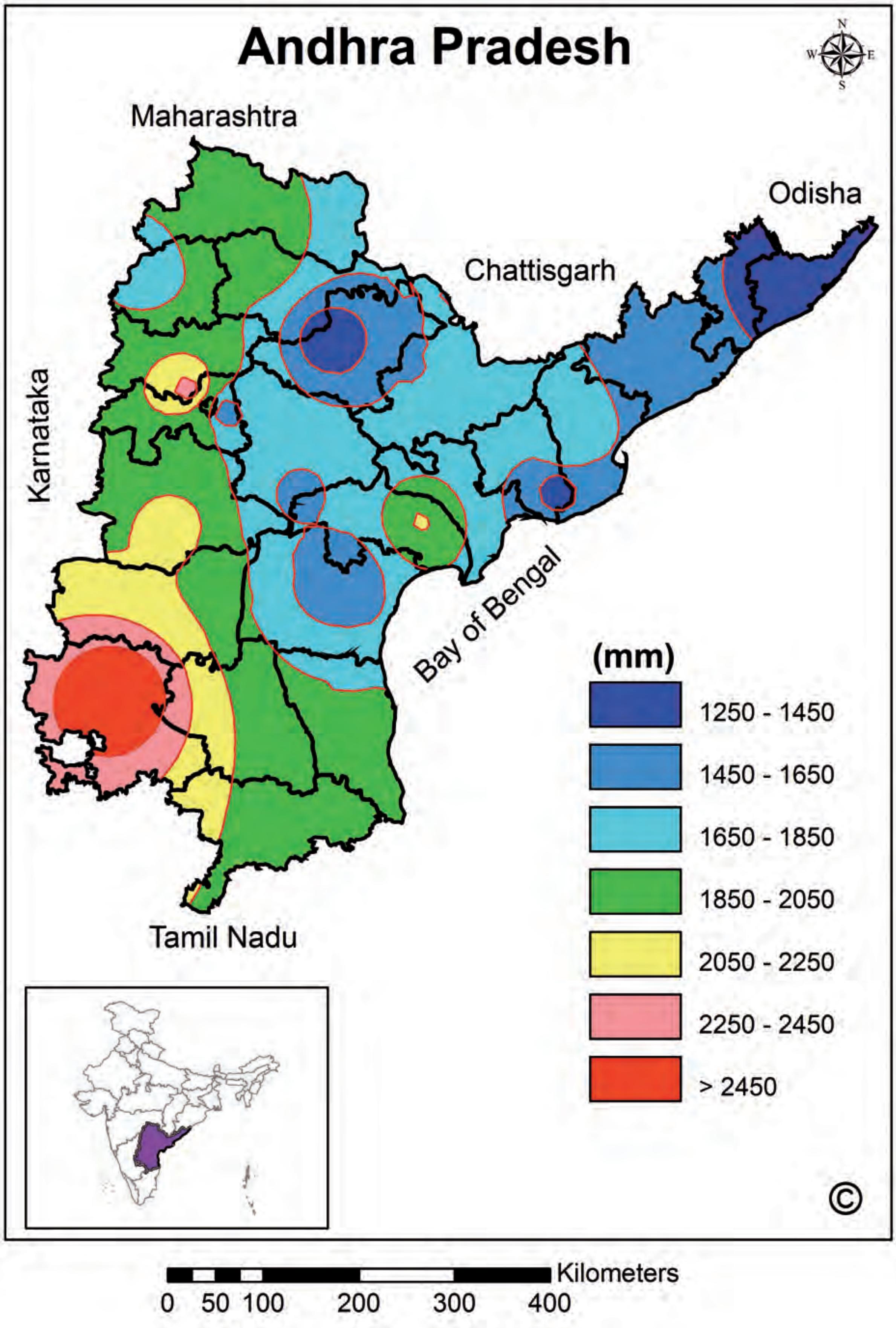


Fig. 126: Annual open-pan evaporation over Andhra Pradesh

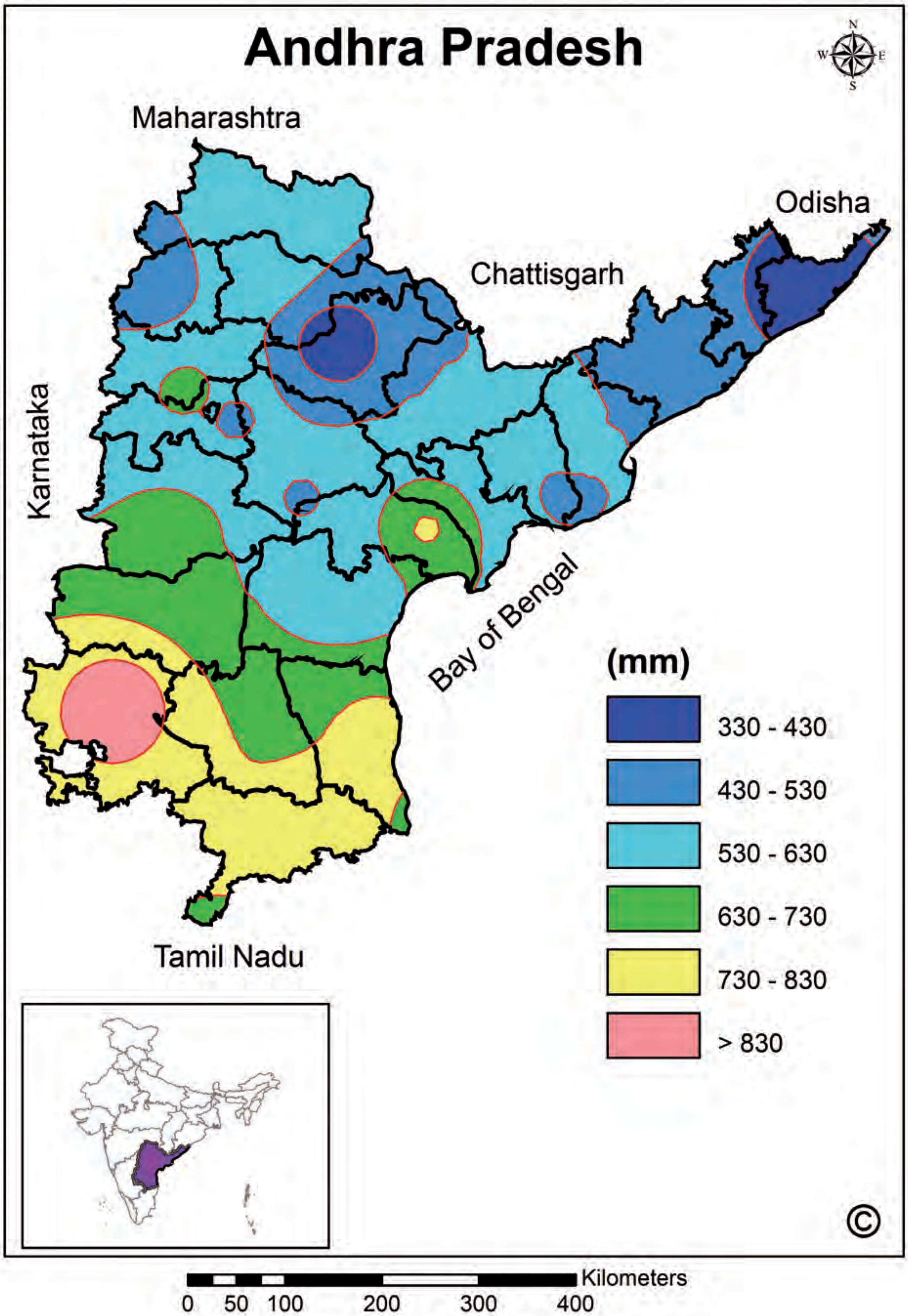


Fig. 127: Southwest monsoon season mean open-pan evaporation over Andhra Pradesh

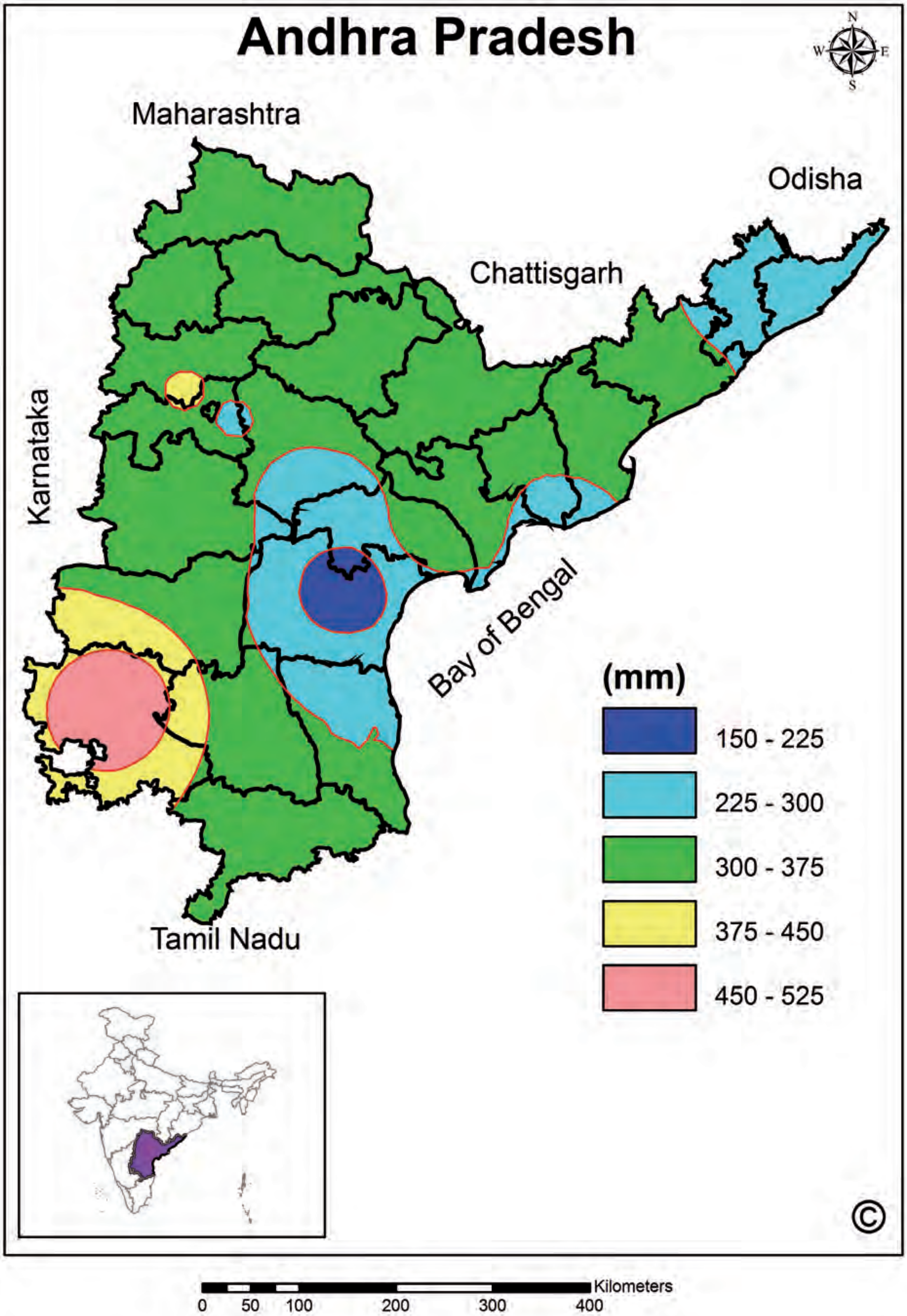


Fig. 128: Northeast monsoon season mean open-pan evaporation over Andhra Pradesh

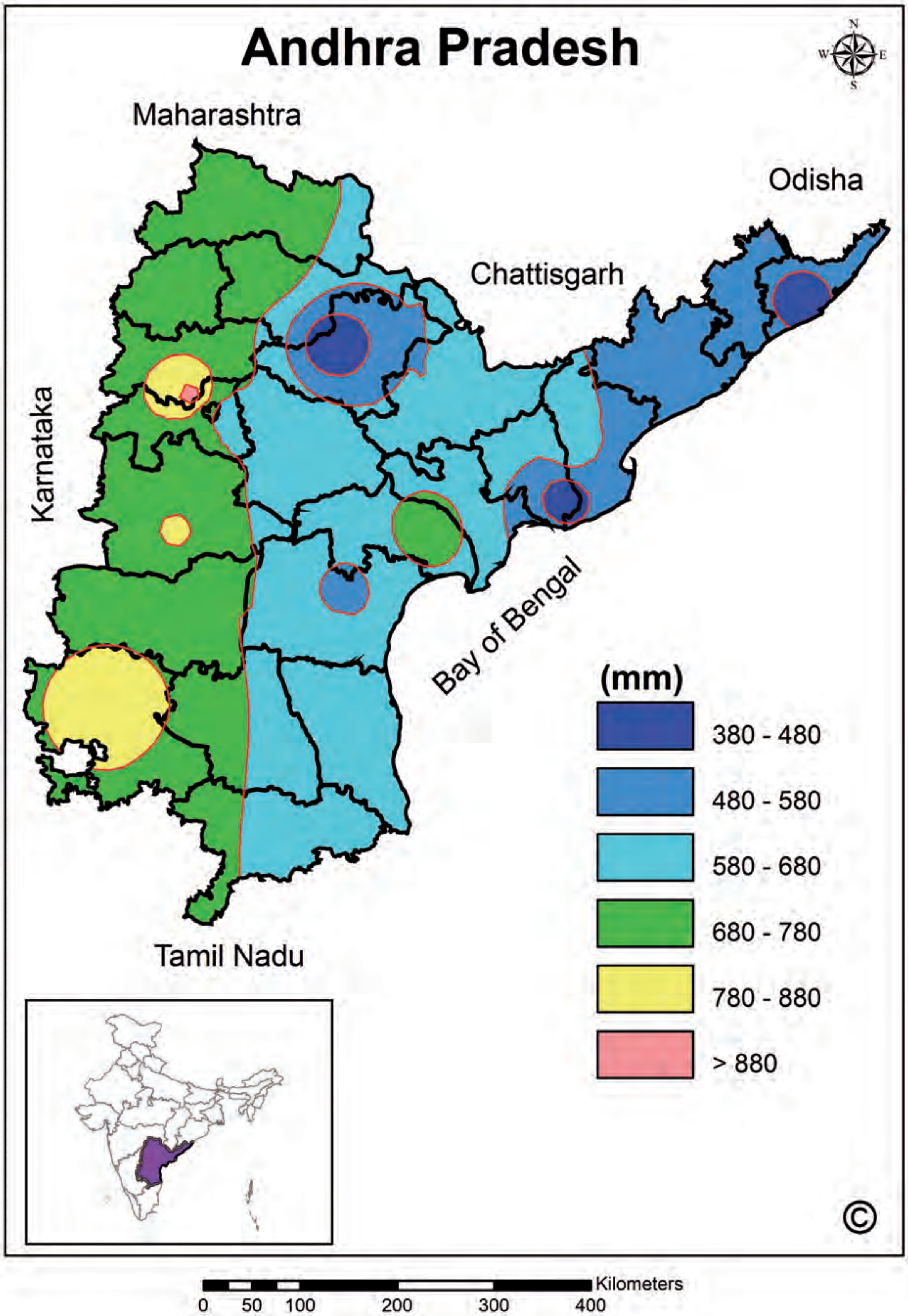


Fig. 129: Summer season mean open-pan evaporation over Andhra Pradesh

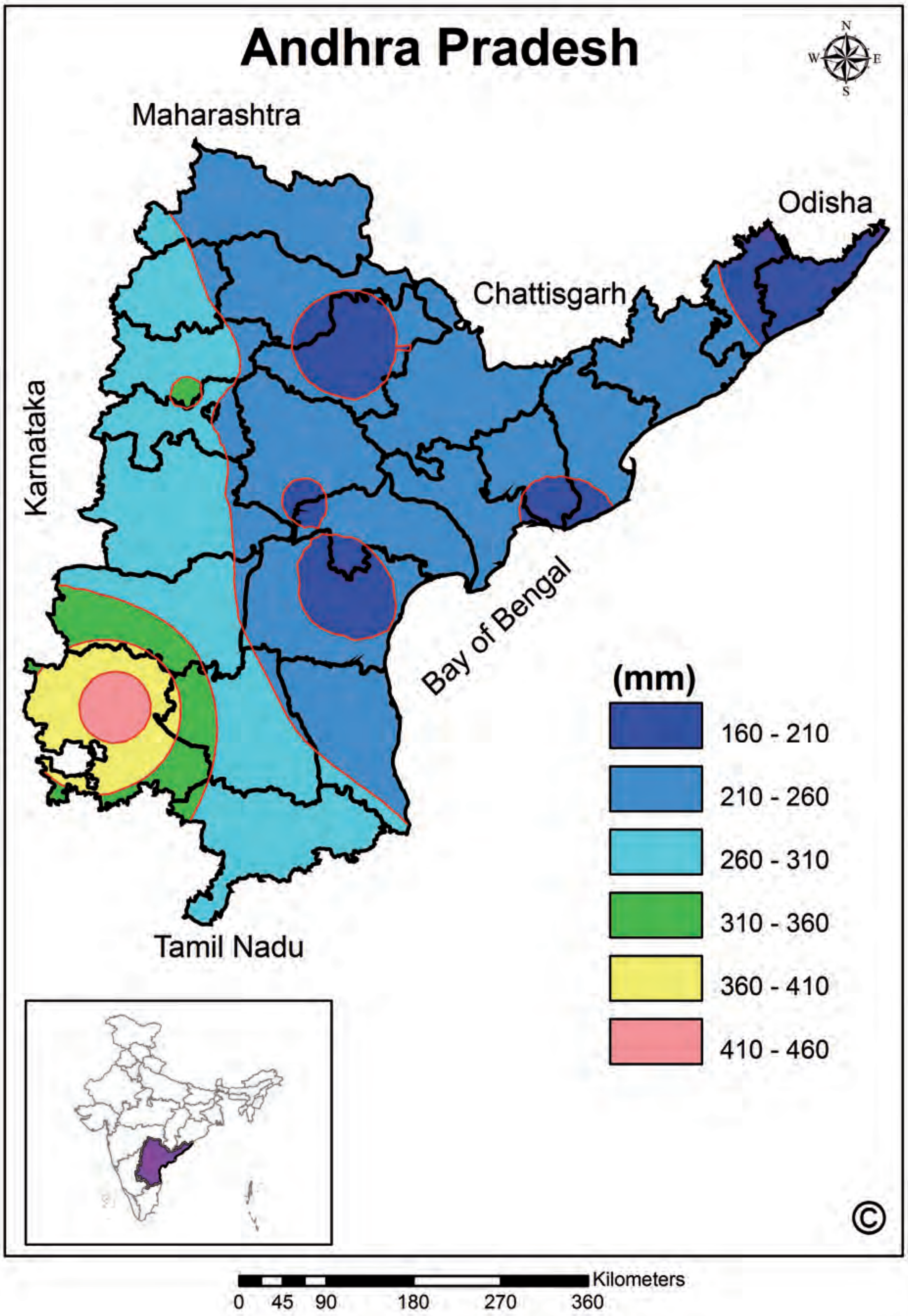


Fig. 130: Winter season mean open-pan evaporation over Andhra Pradesh

10. An in-depth analysis on agroclimatic features of Anantapur district

Anantapur is the only arid district of the state. Frequent drought conditions during the crop season are causing considerable losses to the farmer. Managing the natural resources is vital for this drought prone district. Climatic analysis supported with data on other natural resources should be made use for sustainable crop planning. Here, we present a case study for natural resources and their management to evolve applicable land use plans.

10.1. Climate

Anantapur is one of the drought-prone districts in the rain shadow area of Andhra Pradesh. The annual average rainfall of the district is 546 mm. The spatial distribution of annual rainfall is presented in Fig. 131. Most of the northern parts of the district receive rainfall in the range of 500 to 575 mm whereas most of the southern parts receive in the range of 575 to 650 mm. Parts of D. Hirehal, Bommanahal, Gummagatya, Kudair, Atmakur, Kanaganapalli and Kambadur receive rainfall in the range of 425 to 500 mm. The normal rainfall for the SWM period is 338 mm which is 61.2% of the total rainfall for the year. The rainfall for NEM period is 156 mm, which is 28.3% of annual rainfall (October to December). The remaining months (March, April and May) are warm and dry, when the normal daily maximum temperature ranges between 29°C and 42°C. The months of November, December and January are cool when the minimum temperature is around 17.2°C. The PET is 2140 mm per annum. The aridity index is -73.8, and runoff events average 5 per annum.

10.2. Annual and seasonal rainfall

The annual rainfall of the district ranges between 335 (1985) to 823 (1996) mm with an average of 546 mm (Standard Deviation: 129 mm and co-efficient of variation of 24%) which highlights high degree of inter-annual variability in rainfall pattern (Fig. 132). The seasonal rainfall due to SWM (June-September) ranges between 135 (1994) and 641 mm (1988) with an average of 338 mm (Standard Deviation of 118 mm and co-efficient of variation of 37%). The Kudair, Kambadur and C.K. Palli receive <250 mm mean rainfall during the SWM period, only Mudigubba *mandal* gets >400 mm rainfall. All other *mandals* receive between 250-400 mm rainfall during SWM (Fig. 133). The district also receives rainfall due to NEM which ranges between as low as 30 mm (1989) to as high as 332 mm (1975) with an average of 156 mm (Standard Deviation of 65 mm and co-efficient of variation of 42%).

10.3. Monthly rainfall

The normal rainfall pattern in different *mandals* for different months *viz.,* May to December are presented in Fig. 134 to 141. During the month of May, five *mandals* viz., Rayadurga, Mudigubba, Gummagatya, Madakasira and Penukonda receive rainfall exceeding 60 mm. About 19 *mandals* receive rainfall in the range of 50 to 60 mm. Normal rainfall during the month of June is above 70 mm in eight *mandals* and in the range of 60 to 70 mm in 18 *mandals.* During the month of July, 10 *mandals* receive rainfall exceeding 75 mm. Nine *mandals* only receive rainfall above 100 mm during the month of August and in C.K. Palli *mandal* the normal rainfall is less than 50 mm. During the month of September, all the *mandals* except Pedda Pappuru, C.K. Palli, Gummagatya and N.P. Kunta receive rainfall above 100 mm. Normal rainfall for the month of October for all the *mandals* except Kudair is above 75 mm. Except five *mandals viz.,* Gandalpenta, N.P. Kunta, Kudair, Talupula and Nallacheruvu, all the *mandals* receive less than 60 mm rainfall during the month of November. During the month of December, only 10 *mandals* receive rainfall exceeding 10 mm.

The high variability in Southwest monsoon rain in Anantapur is indicative of the risk associated with farming in this district. The 5-year moving average rainfall pattern of annual, SWM and NEM seasons is depicted in Fig. 142. Out of 40 years of data analyzed for annual rainfall, there are 23 near normal (-19 to +19% of normal), 9 deficit (< -19% of normal) and 8 excess (>19% of normal) rainfall years. During the SWM season, the district rainfall was near normal in 13 years and deficit in 16 years and was in excess for 11 years. There is no consistent declining trend in annual or seasonal rainfall in the district. On the contrary, there is a slight increasing trend in annual and SWM seasonal rainfall which is however statistically non-significant.

10.4. Rainy days

The district receives 548 mm annual rainfall in 32 rainy days with a variability of 18% (Fig. 143). During SWM season, a rainfall on 323 mm occurs in 18 days with a variability of 24%, and during NEM there are 9 rainy events, on average, with a variability of 35%. On average each rainfall event during SWM period produces 18 mm rainfall, which is insufficient to bring the top 45 cm soil to field capacity. The pattern of 5-year moving average showed a statistically significant increasing trend both in annual and SWM in number of rainy days but the same was not evident in the NEM season. The increase in the number of rainfall events has implications in a better temporal distribution of rainfall.

10.5. Spatial and temporal variability in rainfall

The key factor effecting groundnut growth and yield is characterized by the length of the moisture environment during the crop growing season. The variability of rainfall across different *mandals* was analyzed for different time periods which showed that the variability in annual rainfall is high in Atmakur, Rapthadu, Chenne Kothapalle, Roddam *mandal*s in central part of the district and Gorantla, Puttaparthi *mandals* in the southern parts and Bommanahal, Pamidi and Kudair *mandals* on the northern side of the district. The SWM rain was found to be highly variable in the south-eastern and central parts of the district in *mandals* like Mudigubba, Bukkapatnam, Nallamada, Kadiri and Puttaparthi (Figs.144). The variability in annual rainfall in the recent decade (2001-2010) compared to previous decade (1991-2000) showed an increase over north western parts of the district comprising *mandals* of Bommanhal, D. Hirehal, Kanekal, Vidapanakal, Vajrakarur, Rayadurg and Beluguppa (Fig. 145). The variability in June rainfall has increased in the recent decade in Garladine and Singanamala, Putluru, Narpala, Ramgiri and Madakasira *mandals* (Fig. 146) while, the variability in July rainfall has been found to increase in the recent decade in the western and north-eastern parts of the district (Fig. 147). In Gumagutta and Rayadurg *mandals*, the September rain, which is crucial for obtaining optimum yields, was highly variable in the recent decade compared to previous decade (Fig. 148).

10.6. Dependable rainfall (@ 75% probability)

Distribution of expected rainfall at 75 per cent probability for different months starting from May to December in different *mandals* are presented in Fig. 149 to 156. During the month of May seven *mandals* are likely to receive > 16 mm rain, in June two *mandals* may receive > 40 mm rain, in July 14 *mandals* may likely to get > 27 mm rain; during August four *mandals* likely receive > 52 mm rain; during September only Hindupur *mandal* may receive > 90 mm rain and during October two *mandals* (Mudigubba and Vidapanakal) likely to get > 71 mm rain. The dependable rainfall during the months of November and December is above 18 mm in two *mandals* and above 2 mm in one *mandal*, respectively.

10.7. Meteorological drought analysis

To capture the spatial variability of frequency of occurrence of droughts within Anantapur district, the rainfall data at *mandal* (tehsil) level was subjected to drought analysis. Meteorological drought (as per IMD) is defined as the negative departure of annual rainfall from the long term average rainfall at the location. If the departure lies between 11-25% it is considered as mild drought, 26-50% a moderate drought, and if it is >50 per cent it is defined as severe drought. Accordingly, the percentage probability of above droughts for different *mandals* of Anantapur district have been computed and presented in figure 157.

It is seen for Anantapur district (Fig. 157) that the probability of occurrence of mild drought is very low (< 10 per cent) in ten out of 63 *mandals*. However, majority of *mandals* experience mild droughts at 11 to 30 per cent. Only in 3 *mandals* highest probability of mild drought is greater than 30 per cent. The probability of getting 2 to 3 drought years in a decade is noted in 25 *mandals* and highest being noted in Pamidi (33%) followed by Atmakur (31%), Rolla and Yellanur (30%) *mandals*. In six *mandals*, the probability of severe drought is one year in a decade (10%).

The above discussion on the probability of occurrence of drought in Anantapur is based on IMD criteria. Drought probabilities based on SPI for different *mandals* of Anantapur district were computed. Probability for near normal conditions for annual rain is above 50% for all the *mandals* but in two *mandals* (Vidapanakal and Kundurpi) it is less than 50% during SWM season (Fig. 158). Probabilities for moderately wet events on annual basis is above 20% in only B.K. Samudram *mandal* and during SWM season it is above 20% in three (Vidapanakal, Ramagiri and Somandepalli) *mandals* (Fig. 159). Probabilities for very wet events and extremely wet events are presented in Fig. 160 & 161. Probability for moderately dry conditions on annual basis is above 20% in Gooty and Chilamatur *mandals* and during SWM season, it is above 26% in Agali *mandal* (Fig. 162). Likewise, probability for severely dry conditions on annual basis is above 6% in 17 *mandals* and in six *mandals* it is above 11% during SWM season (Fig. 163). Probability for extremely dry condition on annual basis is 6% in Narpala *mandal* and during SWM season in Talupula *mandal* the probability for extremely dry conditions is seven per cent (Fig. 164).

10.8. Length of growing season

The normal onset of the monsoon is in June but could be delayed up to end of August. The length of growing period is variable across *mandals* spanning from 91-161 days (Fig. 165). While the 8 *mandals* (Yellanur, Garladinne, Kudair, Narpala, Atmakur, Settur, CK Palli, Roddam, and Amarapuram) have an LGP of 91-112 days; 29 *mandals* have LGP range from 119-140 days. Rest of the 25 *mandals* have LGP of 141-161 days.

Based on this, three crop growing situations were delineated for the district. Here also, the distribution of the rainfall during critical crop phenophases is vital for harvesting good yields. In the remaining *mandals*, the LGP ranges between 120-150 days which can support cultivation of bunch type groundnut cultivars. However, the trend analysis of yield data of last 13 years across *mandals* does not indicate any relationship with yields and LGP. The spatial distribution of onset and withdrawal of Southwest and Northeast monsoons are presented in Fig. 166.

10.9. Rainfall trends

Mann-Kendall test, a non-parametric statistical trend test was employed to estimate whether any significant trend of rainfall exists or not. *Mandal* level daily data was used in the trend analysis. It is seen from the figure 167, that variability among the *mandals* with respect to annual rain totals is more compared to the SWM rain. Greater number of *mandals* in the Anantapur district have not shown any trend. Increasing trend is observed in 12 *mandals* in annual rainfall *viz.,* two at Bommanahal and Atmakur *mandals* (1% significant level), six at Guntakal, Rayadurgam, Roddam, Amarapuram, Gorantala and Chilamathur showed significant trend at 5% level and at 10% significance of an increasing trend in four *mandals* namely Uravakonda, Bukkapatnam, Penukonda and Nallamada in Anantapur district. No decreasing trend in annual as well as SWM rainfall has been observed in any *mandal*. This is in conformity with the earlier findings that the districts total rainfall showed an increasing trend in the recent decades. During the SWM period, only two *mandals i.e.,* Atmakur and Gorantla showed increasing trend at 5% and 10% level of significance, respectively.

10.10. Analysis of heavy rainfall events

Frequency of heavy rainfall events of the order of 75 – 100 mm and more than 100 mm per day during SWM period were calculated at *mandal* level data. The results revealed that in Raptadu *mandal* rainfall events more than 100 mm on annual basis showed a decreasing trend at 1% significance level. In the 75-100 mm category, on annual basis declining trends are observed in Tadimarri *mandal* at 5% and in Uravakonda and Kadiri *mandals* at 10% (Fig. 168). During SWM season declining trends are observed in Tadimarri and Uravakonda *mandals* at 5% and in Atmakur *mandal* at 10% (Fig. 169). Though a significant increase in annual rainfall is recorded in Atmakur and Uravakonda *mandals* perhaps the increase in number of small intensity storms may have contributed to increased rainfall in these *mandals*.

10.11. Drought and crop phenology

Groundnut crop is extensively cultivated in Anantapur district. It is a hardy crop that can withstand intermittent dry spells, the crop yields are affected when prolonged droughts occur at critical phenophases of the crop. In the Anantapur district, the predominant cultivar TMV2 is grown. It is sensitive to soil moisture deficit at pegging and pod development stages (Table 27).

Table 27: Impact of soil moisture stress on Groundnut pod yield

Period of drought	% reduction in pod yield
Flowering and pegging	16.6
Flowering, pegging and late pod filling	28.6
Pegging through maturity	87.0
Pod filling	45.6
Mid pod filling	18.6

10.12. Influence of length of dry spell

Rainfall in Anantapur district was found to be highly erratic and variable. It leads to droughts of varying intensities and durations in the crop season. Drought directly and physically reduces crop's vegetative growth thereby reducing cell turgor. When groundnut is grown under rainfed condition with in a high variable rainfall environment, long-term drought results in both reduced vegetative and ontogenetic growth stage.

The effect of length of dry spell at different growth stages on groundnut on pod yield at Anantapur has indicated that yields decline if the moisture stress exceeds in duration for three weeks or more in the early vegetative stage (0-35 days after sowing (DAS)) (Fig. 170).

The impact of drought is more pronounced during start of pegging and seed development (51-85 DAS). Pod yields decline drastically in years when the length of dry spell exceeded 30 days during this stage (Fig. 171). Frequent failure of monsoon rains during these critical periods is the crux of the failure of groundnut crop in the district.

10.13. Agricultural planning based on agroclimatic analysis and natural resources

Despite several efforts, no crop could successfully replace groundnut in the district. A trend analysis of groundnut area, production and productivity showed that a substantial increase in area over years was with slight deviations in some years. On the other hand, the production and productivity did not show any consistent trend (Fig 172). During 2007, largest area of 8.6 lakh ha under groundnut was recorded with a production of 11.02 lakh tons and a productivity of about 1200 kg ha^{-1} which highlights the fact that there is a possibility of realizing more than 1 ton per ha productivity even in farmers' fields. On the other hand, extremely low yields were also recorded during 2006 and 2008. When compared, during 2006, annual and seasonal rainfall were 434 and 202 mm, respectively whereas in 2008, they were 762 and 436 mm, respectively which again emphasizes that the key to realizing stable yields of groundnut in Anantapur is the distribution of rainfall rather than total. The peg penetration and pod development stage are highly sensitive to dry spells and hence distribution becomes important.

The district level yield data were plotted against seasonal rainfall to find out optimum levels of seasonal rainfall required for obtaining higher yields (Fig. 173). A rainfall of 350 mm appears to be critical for obtaining minimal yield of 350 kg ha^{-1}. When the seasonal rainfall is above 350 mm, the probability of realizing an yield of 1 ton and more is about 50%. It appears that during some years, despite high seasonal rainfall, lower yields were realized which signifies improper distribution of rainfall. Trends of *mandal*-wise yield of groundnut over last 13 years was analyzed to group *mandals* into different production classes (Fig. 174). Accordingly, the *mandals* were grouped into three classes based on mean annual yield of the *mandal* viz. <400 kg ha^{-1}; 400 to 500 kg ha^{-1} and >500 kg ha^{-1}. Fifteen *mandals* (D. Hirehal, Kudair, Beluguppa, Kalyandurg, Rapthadu, Tadimarri, Kambadur, Kanaganahalli, Ramagiri, Penukonda, Roddam, Madakasira, Gudibanda, Rolla and Parigi) showed less than 400 kg ha^{-1} yield levels, 30 *mandals* (Vajrakarur, Bommanahalli, Uravakonda, Kanekal, Garladinne, B.K. Samudram, Karpala, Anantapur, Atmakur, Yellanur, Bathalapalli, Brahmasamudram, Settur, Kundurpi, Dharmavaram, Mudigubba, C.K. Palli, Bukkapatnam, Talupula, Gandlapenta, N.P. Kunta, Nallacheruvu, O.D. Cheruvu, Tanakal, Gorantla, Somandepalli, Hindupur, Lepakhsi, Agali and Amarapuram) could realize 400-500 kg ha^{-1} where as remaining 18 *mandals* showed more than 500 kg ha^{-1}.

The following areas where the thrust could be laid.

- Identification of suitable groundnut-based farming systems
- Crop diversification based on soil and weather conditions

10.13.1. Groundnut based farming systems

Groundnut occupies largest area (8 lakh ha) in the district. As such, it is not possible or prudent to replace groundnut immediately, as there is no other crop which is as resilient as groundnut suited to the rainfall pattern of the district. Hence, there is a need to identify gaps in present groundnut production systems and address the issues. Some of the issues are discussed below.

10.13.2. Delineation of regions suitable for groundnut

The district plants around 5-9 lakh ha of area under groundnut annually. However, considering the soil type, topography, and rainfall distribution pattern, a reasonable area is really not fit for groundnut. Immediate efforts should be made to delineate such areas which are distributed across all the 63 *mandals*. A comprehensive survey has to be undertaken to map these regions. Such delineation will help classification of regions best fit for groundnut where vertical promotion of groundnut should be focused. In regions that support groundnut but also need alternate crops/allied activities for drought proofing and sustainable livelihoods, action research should be focused by integrating groundnut with other livelihood opportunities to demonstrate viability and economic feasibility. The marginal lands which are not at all fit for groundnut must be targeted for forestry/pastures etc.

It is suggested that the entire *rabi*-summer groundnut area in the district must be tapped in a systematic way to meet the seed demand. It must start with providing improved cultivars seed material to these farmers by the Acharya N.G. Ranga Agricultural University (ANGRAU) / Directorate of Groundnut Research (DGR) and right from the beginning of the season, the crop must be monitored to ensure that crop is well protected from biotic and abiotic stresses. The produce must only be directed for seed purpose. To promote such activity, all the farmers registered under seed program may be provided with technical support, drip/sprinkler systems, and improved seeds for multiplication.

Further, a satellite-based mapping of *mandal*-wise irrigation sources of the district has to be done to divert the paddy area of *rabi*-summer towards groundnut seed production which will help in substantial increase in water productivity. For entire district, 4-5 seed hubs could be developed where the seeds of 4-5 improved cultivars accepted by farmers must be multiplied. This will also help in maintaining varietal mosaic instead of monocropping with same cultivars throughout the district which is also not good from the point of view of outbreak of epidemics of biotic stresses.

10.13.3. Drought tolerant cultivars

The water requirement of groundnut is around 500-700 mm depending on the region and soil type. However, the crop can also come up very well in regions with less rainfall provided the same is well distributed. Of late, the August rainfall in the district has become more uncertain. Cultivars which can tolerate prolonged stress during re-productive stage need to be bred urgently. The erratic distribution of rainfall during recent years is leading to prolonged dry spells during crop season and thereby resulting in crop losses. In Anantapur district, either Spanish bunch or Virginia bunch type of groundnuts is in vogue with duration of 110-135 days. The currently cultivated groundnuts can with stand up to 4 weeks of continuous dry spell. The All India Coordinated Research Project (AICRP) centre of groundnut stationed in Kadiri is claiming cultivars with about 45 days of drought tolerance. Research must be strengthened for development of genotypes that can with stand prolonged dry spells without foregoing pod yield and biomass as both are economically important.

The present cultivars like K-6 and Narayani are well accepted by the farmers and are gradually replacing TMV-2. Development of early maturing (90 days) drought-tolerant groundnut cultivars and also those suitable late-sown conditions for areas receiving delayed monsoon may be targeted. Similarly, stay-green type of groundnut cultivars can be developed and promoted for this purpose. So far as drought proofing in groundnut is concerned, it can be attained mainly by developing short-duration and mid-season drought tolerant cultivars which would naturally escape end-of-the-season drought.

10.13.4. Groundnut based cropping systems research

There is an urgent need to identify and demonstrate suitability and economic viability of groundnut-millet; groundnut-pulses; groundnut-castor and similar cropping systems. Such trials must be planned across the district in action research mode. Research on development of groundnut-based integrated farming system models with small ruminants is needed to bring stability, income and resilience to small holders/marginal/SC/ST farmers.

Cultivation of minor millets need to be promoted where the soils are very shallow and the probability of groundnut failure is more than 60%. The District Administration, however, should institutionalize the procurement of millets and their inclusion in the mid-day meal scheme.

Pigeonpea cultivars *viz*., LRG 30, LRG 41 and Asha are being grown mostly in intercropping systems. The cultivars from University of Agricultural Sciences (UAS), Bangalore viz., ‘BRG 1’ and ‘BRG 2’ and the cultivar from Badnapur ‘BSMR 761’ may be tested in Front-line Demonstrations (FLDs) and the best performing cultivar may be promoted.

There is lot of scope for promotion of chickpea in black soils. At present the prominent cultivar is ‘JG 11’. The latest cultivar ‘JAKI 9218’ which is very popular and high yielding may be promoted in the district. The groundnut (intercropped with pigeonpea and caster) - chickpea cropping system is ideal for the district. However, if one or two supplemental irrigations are provided, nearly 30% yield increase can be obtained in both the seasons.

10.13.5. Water management

The district receives mean annual rainfall of about 572 mm. However, across *mandals* the rainfall ranges between 381 and 693 mm. This rainfall is received from both South-west and North-east monsoons. On an average the district has only 5 run-off events per annum. Under this situation, there is a need for harvesting the rainwater for its judicious use during critical crop growth phases. Such harvesting also helps in improving the day-by-day dwindling groundwater situation. This objective could be achieved through a two-pronged approach i.e. by improving water holding capacity of the existing water bodies and creating on-farm storage facility.

10.13.6. Renovating existing water bodies

As per the information available in the previous reports, the district has 5824 water bodies out of which 1373 are big tanks, 2094 are small tanks and 203 are spring channels. A survey conducted in Dhone and Kalyandurg *mandal* shows functional and defunct water bodies (Fig. 175).

Such efforts should be made for the entire district so that exact situation of the water bodies could be obtained. A national pilot project "Repairs, Renovation and Restoration (RRR) of water bodies" directly related to agriculture funded by Government of India and State Government of Andhra Pradesh was undertaken for Anantapur and Mahabubnagar districts by the A.P. Irrigation Department. In the 1st phase of the project 52 water bodies were targets to cover an ayacut area of 8756 ha. Such efforts should be continued with a transparent implementation strategy so that all tanks are restored in a stipulated time.

Many tanks have been silted and the water storage capacity has come down sharply affecting the recharge in the neighbouring open and tube wells. There is an urgent need for de-silting all these tanks and use the silt (after testing) for improving the soil texture and water holding capacity of the red soils. Since this district is highly drought prone, improving the moisture holding capacity of soils is an essential requirement.

10.13.7. On-farm water harvesting

Farm pond technology has been developed and successfully demonstrated in Anantapur district by several agencies. This technology has been shown to benefit the farmers to provide supplemental irrigation to the crops at critical growth stages. Similarly, percolation tanks have also been demonstrated successfully. These technologies could not reach farmers due to high capital investment.

The success story of Indore can be emulated where in black cotton soils the rain water is harvested and used for cultivation of chickpea during *rabi*. The dimensions of the farm ponds are different and they should also be promoted through Mahathma Gandhi National Rural Employment Gurantee Act (MGNREGA).

10.13.8. Artificial recharge of groundwater

Artificial recharge has to be created in over exploited areas of ground water by construction of rain water harvesting structures, dug out ponds, percolation tanks and feeder channels. This is applicable to 30 *mandals* of the district (Peddappapuru, Kayanadurg, Parigi, Anantapur, Madakasira, Bramhasamudram, Rapthadu, Tadipatri, Yellanur, Putlur etc.).

Recharge pits can be constructed at drainage divides, which fit well in areas with weathered and fractured aquifer material and fissured granites with good to moderate infiltration capacity with moderate runoff. They help in percolation of stored water and in increasing soil moisture. All the possible sites for construction of check dams and percolation tanks have to be well utilized for enhancing ground water recharge. The scope and possibility of construction of Kolhapur type weirs may be explored in the selected pockets of the district.

10.13.9. Other approaches

Improvements are to be made in on-farm water management techniques to reduce ground water draft or pumping. The percent utilization of created ground water potential of the district has to be improved for limiting the over exploitation in *mandals* like Chilamathur, Agali, Madakasira, Gudibanda, Raptadu and Kalayanadurg. This will also help in limiting ground water exploitation in critical category *mandals* like Atmakur, Belugappa, Amadaguru, Singanamala and Puttaparthy. This can be achieved by improved irrigation methods like drip and micro sprinkler irrigation.

Between 3rd and 4th minor irrigation census (2001 and 2007), the share of dug wells in total ground water extraction devices have declined from 58.7% to 33.3%. The defunct open dug wells in *mandals* like Madakasira, Raptadu, Putlur, Anantapur, Kalyanadurg and Parigi can be well utilized as ground water recharge structures by provision of filters made with gravel or any other locally available materials.

In case of availability of excess surface runoff in localized depressions in the agricultural fields, sub surface recharge structures such as recharge shafts or recharge cavities can be used for better ground water recharge. In case of *mandals* like Rayadurg, Kanekal, Belugappa, Gooty, Guntakal, Putlur, Vajrakarur, Vidapanakal, Yadiki and Yallanur where heavy soils (black cotton soils) restrict the infiltration of rain water in to the soil profile, provision of recharge shafts have to be made along with water harvesting structures like check dams and percolation tanks. The ground water in *mandals* like Mudigubba, Gooty, Kanekal, Guntakal and Vidapanakal is developed at the levels and 30%, due to poor quality of water. To tackle this problem, conjunctive use of ground water along with harvested rain water is to be encouraged, wherever possible.

10.13.10. Promotion of cluster beans

About 10-15 blocks are also suitable for cultivation of clusterbean for gum production. Trials carried out by Arid-legumes project in the past showed that 600-800 kg ha^{-1} yield can be obtained under rainfed conditions. However, due to lack of market support this initiative could not go forward earlier. Now, a time bound action plan need to be chalked out for promoting clusterbean for gum production in which the State Department should take the major initiative to procure the seeds from Central Arid Zone Research Institute (CAZRI), Jodhpur and have a buy back arrangement initially to popularize its cultivation. Simultaneously marketing arrangements have to be made by tying up with the industry most of which are presently located in Rajasthan.

10.13.11. Promotion of alternative crops

In recent years, castor crop has been cultivated in some *mandals*. However, the performance of the crop during *rabi*-summer is very good and it has been paying good dividends to the farmers. On the contrary, during odd years when the monsoon does not break even by August, castor cultivars could be promoted as any rains during later period could result in yield as the crop puts up primary, secondary and tertiary panicles. In 15-20 blocks, castor (cultivars in *kharif* and hybrids in *rabi*) can be promoted which can give more returns than groundnut either as sole or as intercrop with cluster bean.

Similarly, there is a sharp rise in maize and pigeonpea. So, efforts must be made to spread suitable cultivars of these crops so that farmers get maximum benefit. The area under chickpea is also on the rise especially in *mandals* with black cotton soils. These regions need support in terms of genotypes that could be cultivated under residual moisture conditions.

The possibilities for promotion of high value medicinal and aromatic plants like Aloe vera, lemon grass, and other crops along with suitable marketing facility may be explored. The modalities may be in the form of large scale demonstrations.

10.13.12. Arid horticulture

The district is promoting arid horticulture under various schemes such as National Horticulture Mission (NHM), PKVY and MGNREGA. Research should be conducted for primary value addition at farm level for enhanced incomes at the farm. Similarly, selective horti-pastural systems and horti-agri systems must be developed depending on the soil type, soil depth and LGP. As the *mandals*' agroclimatic conditions are diverse, the models should be specific to the *mandals*. Crops like pomegranate, sweet orange and papaya were observed to be suffering from biotic and abiotic stresses. There is an urgent need for the transmission of available technology through off-beat technology transfer methods.

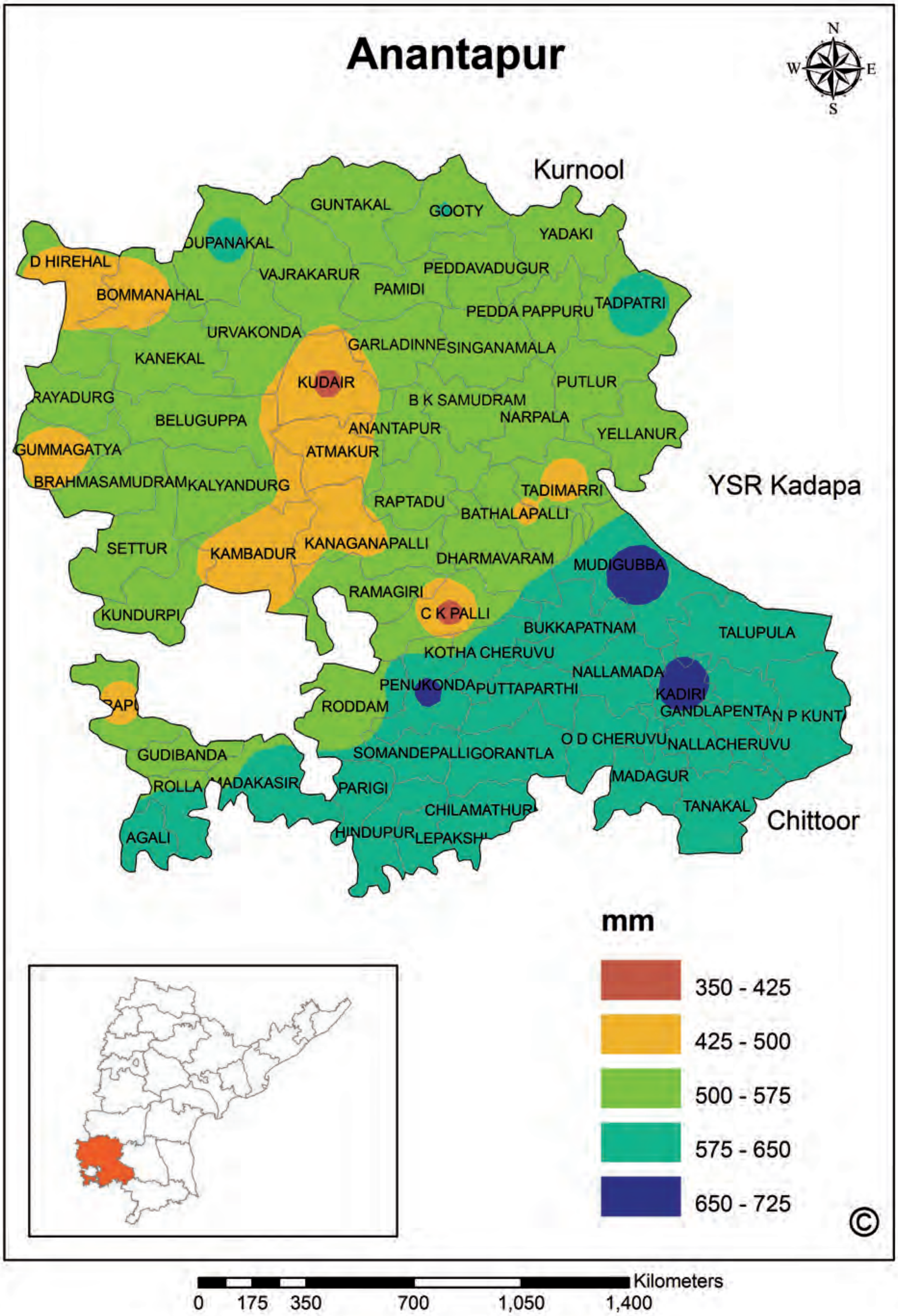


Fig. 131: Mean annual rainfall distribution in different *mandals* of Anantapur district (Values spatially interpolated)

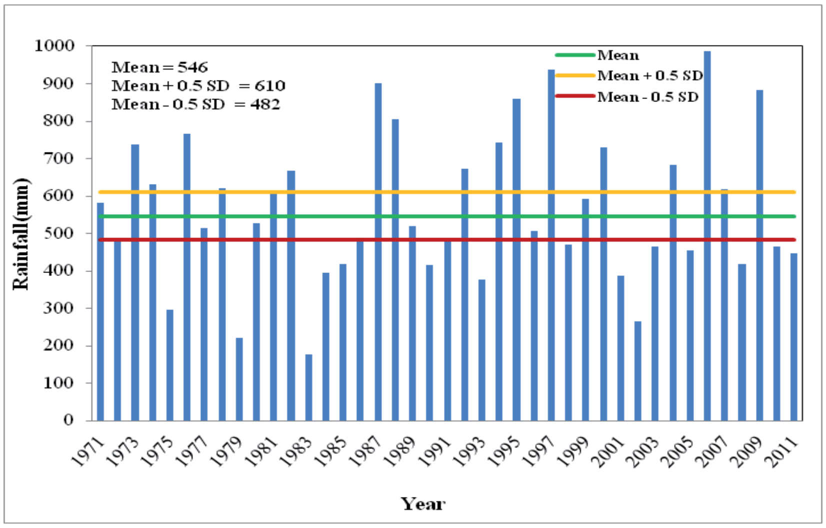


Fig. 132: Variation in annual rainfall of Anantapur district (1971-2011)

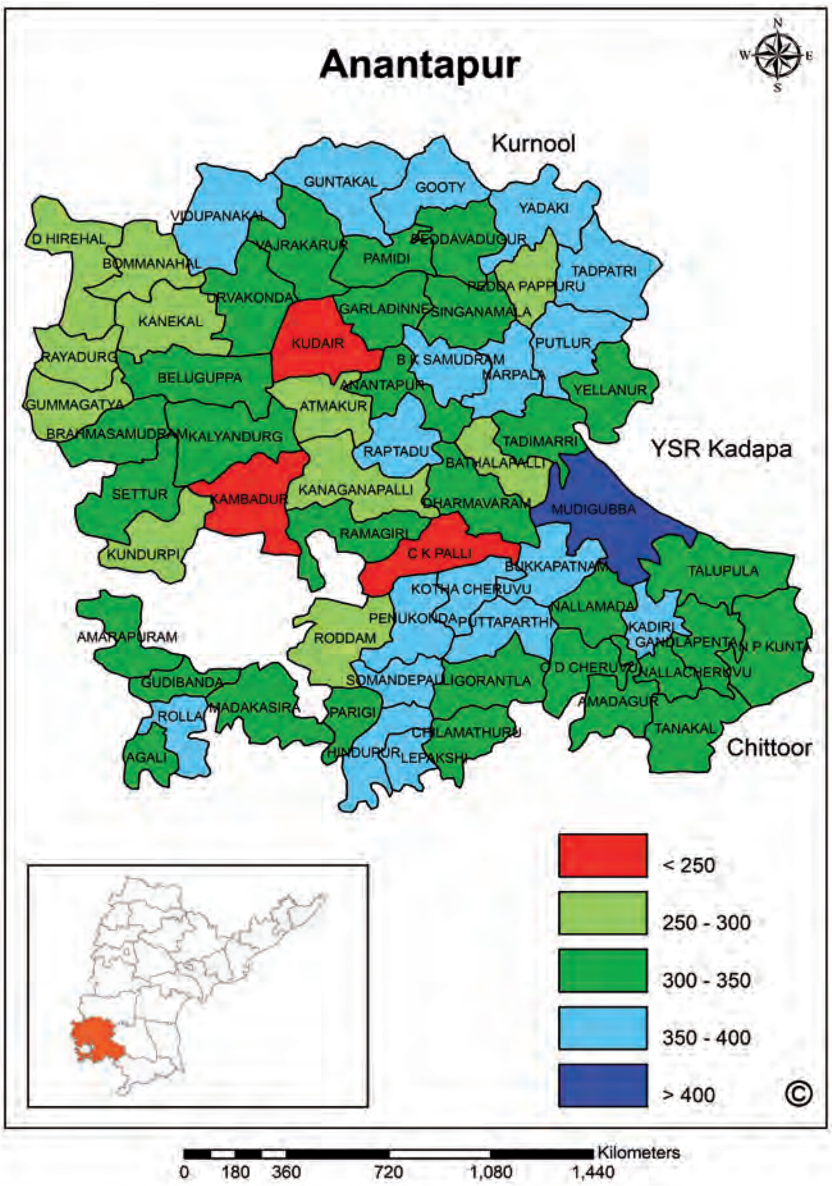


Fig. 133: Mean Southwest monsoon season rainfall distribution in different *mandals* of Anantapur district

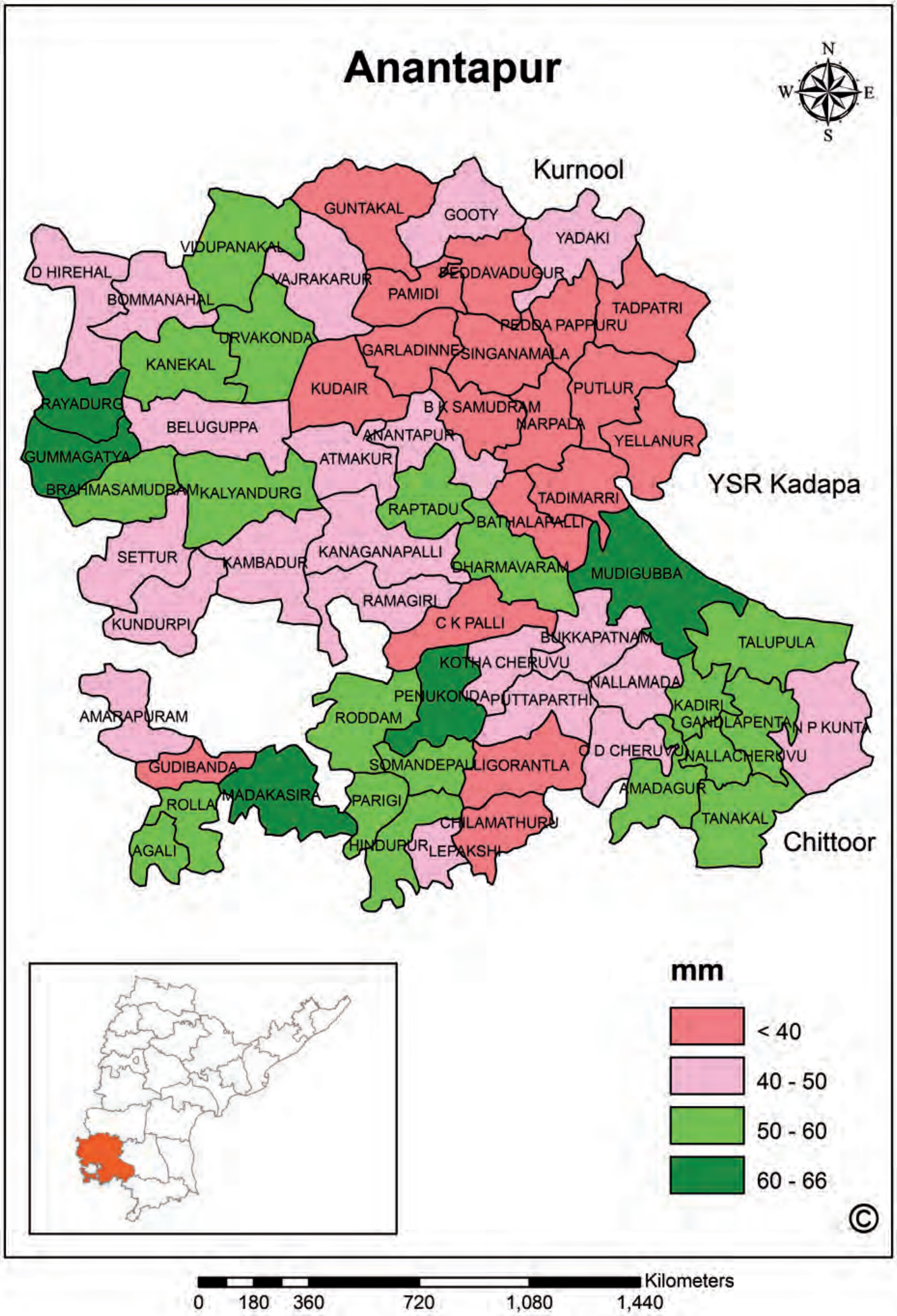


Fig. 134: Normal rainfall during the month of May in different *mandals* of Anantapur district

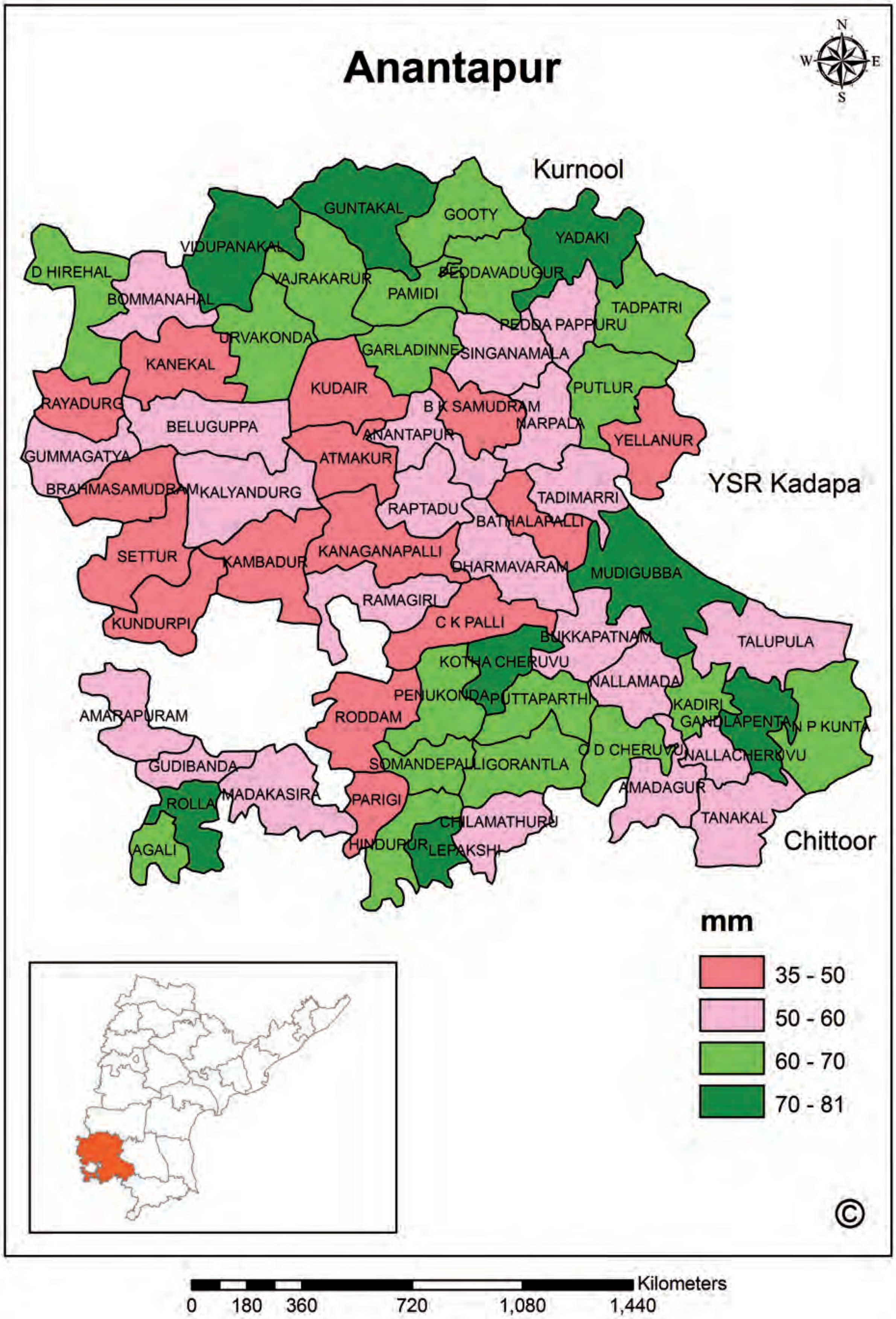


Fig. 135: Normal rainfall during the month of June in different *mandals* of Anantapur district

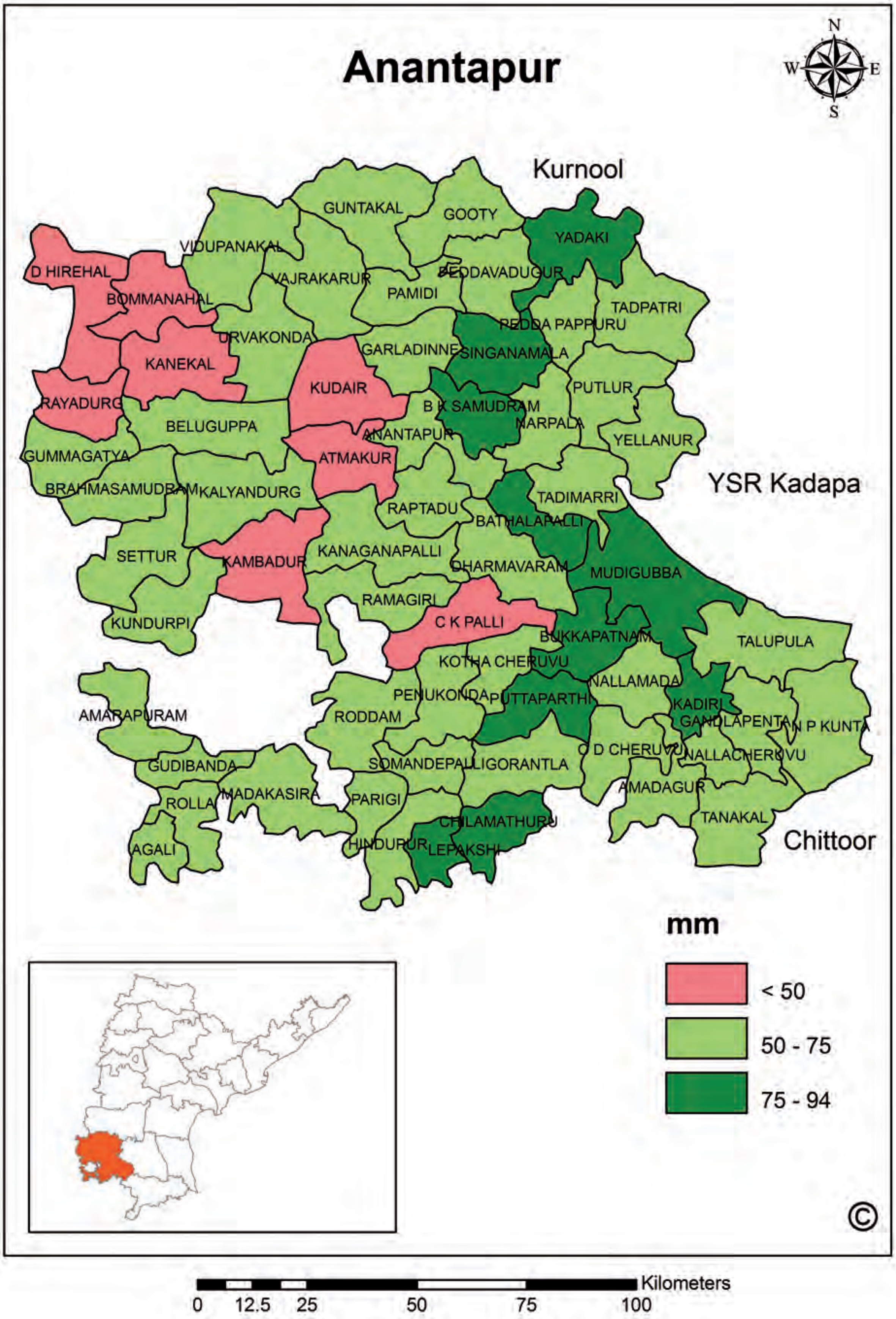


Fig. 136: Normal rainfall during the month of July in different *mandals* of Anantapur district

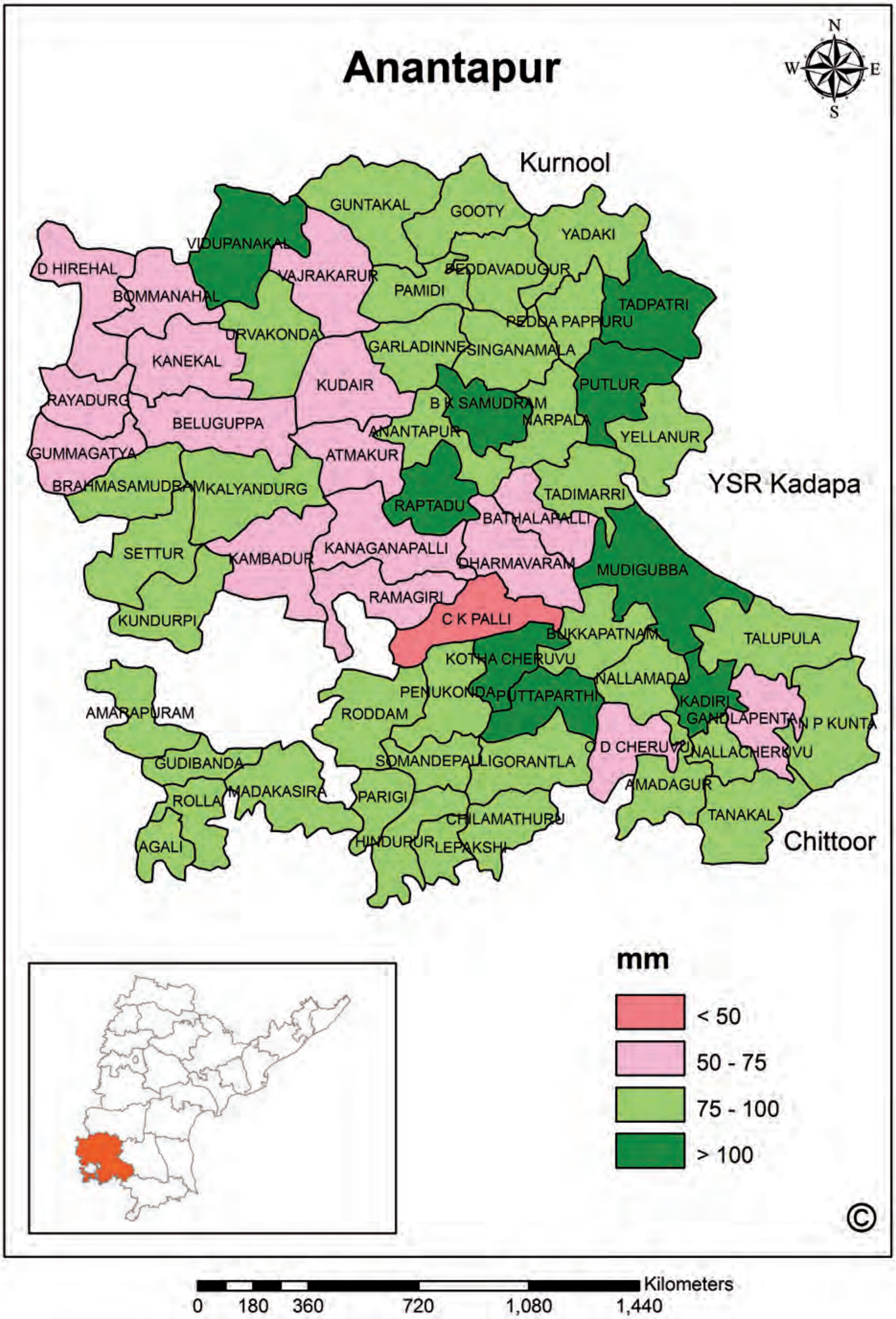


Fig. 137: Normal rainfall during the month of August in different *mandals* of Anantapur district

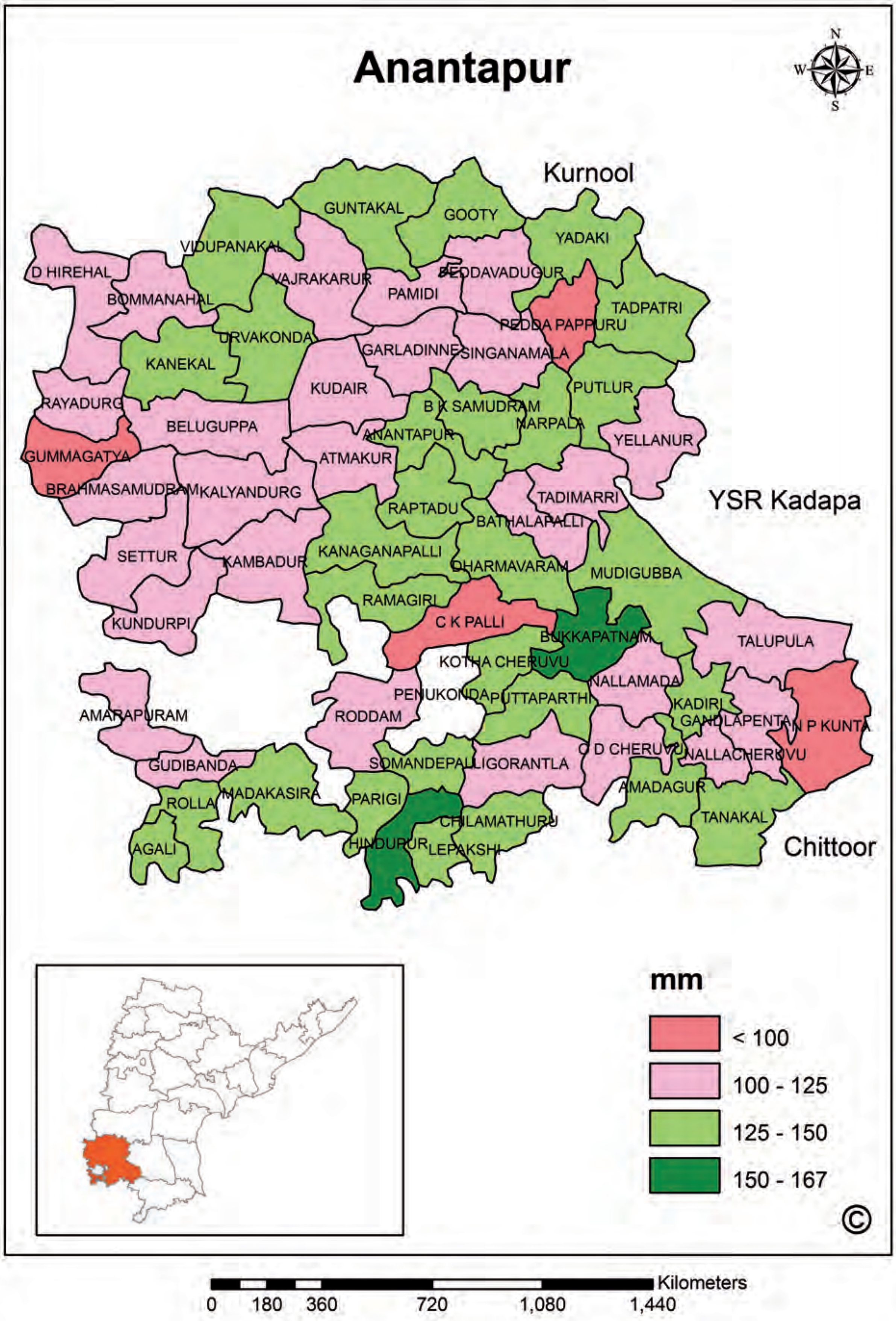


Fig. 138: Normal rainfall during the month of September in different *mandals* of Anantapur district

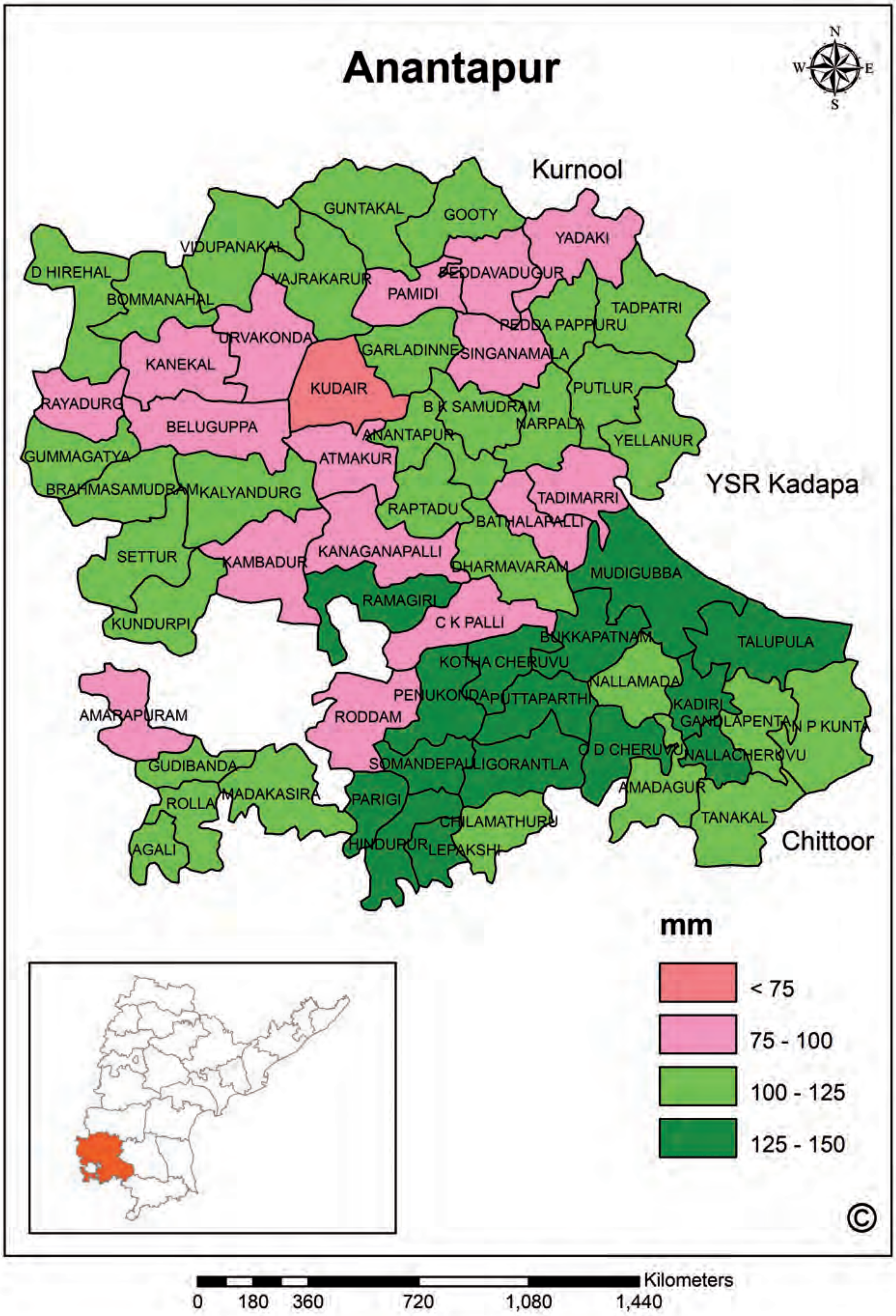


Fig. 139: Normal rainfall during the month of October in different *mandals* of Anantapur district

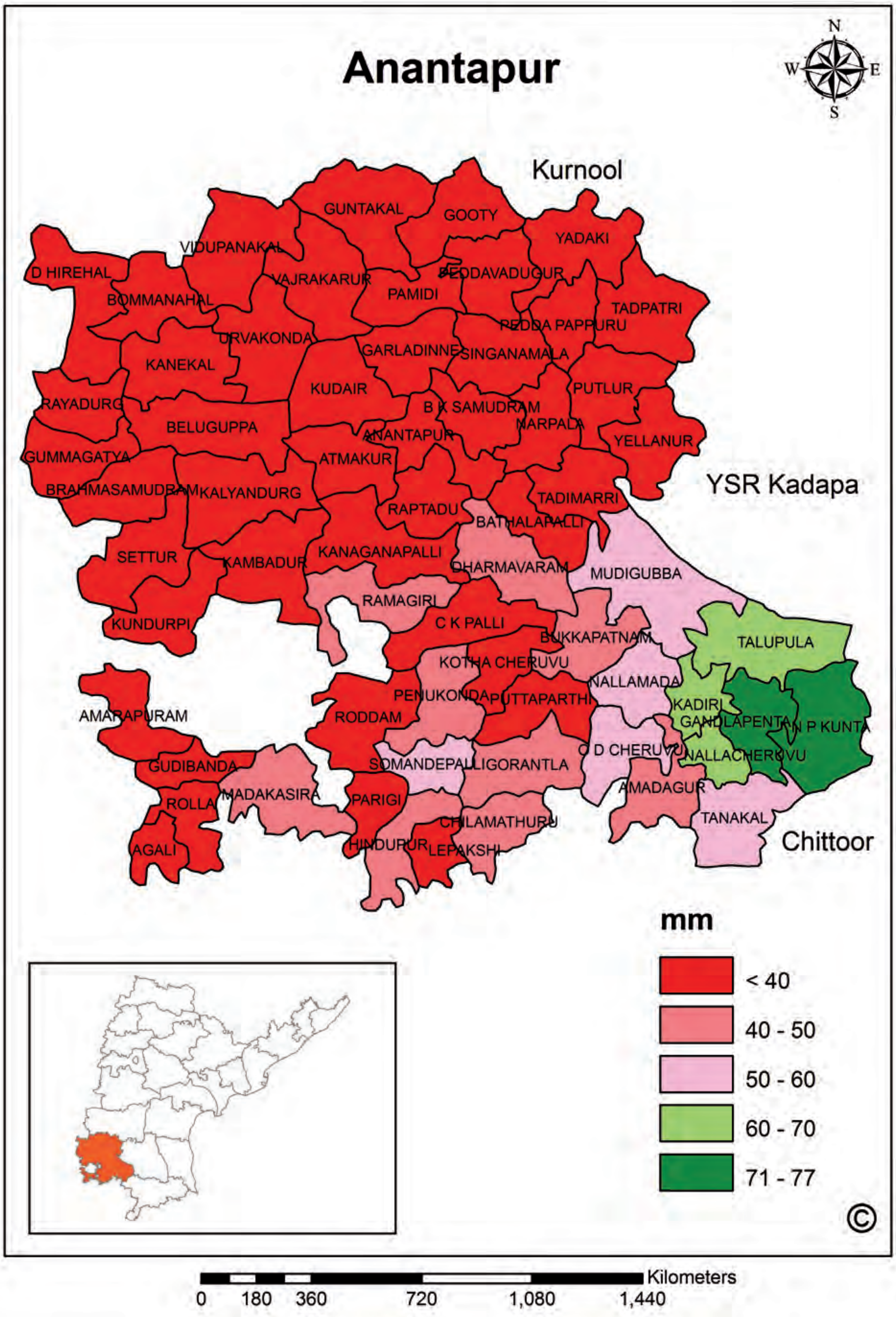


Fig. 140: Normal rainfall during the month of November in different *mandals* of Anantapur district

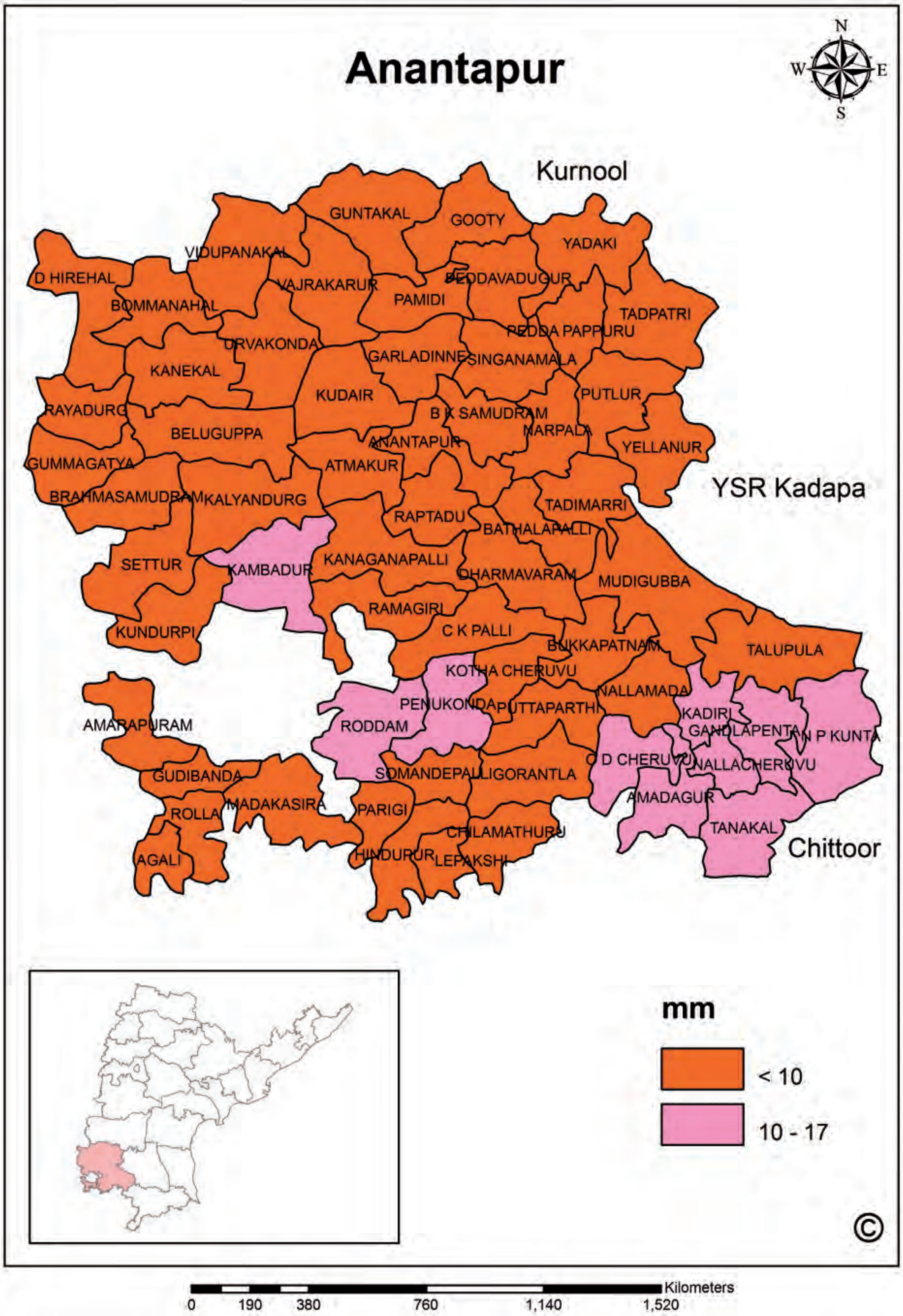
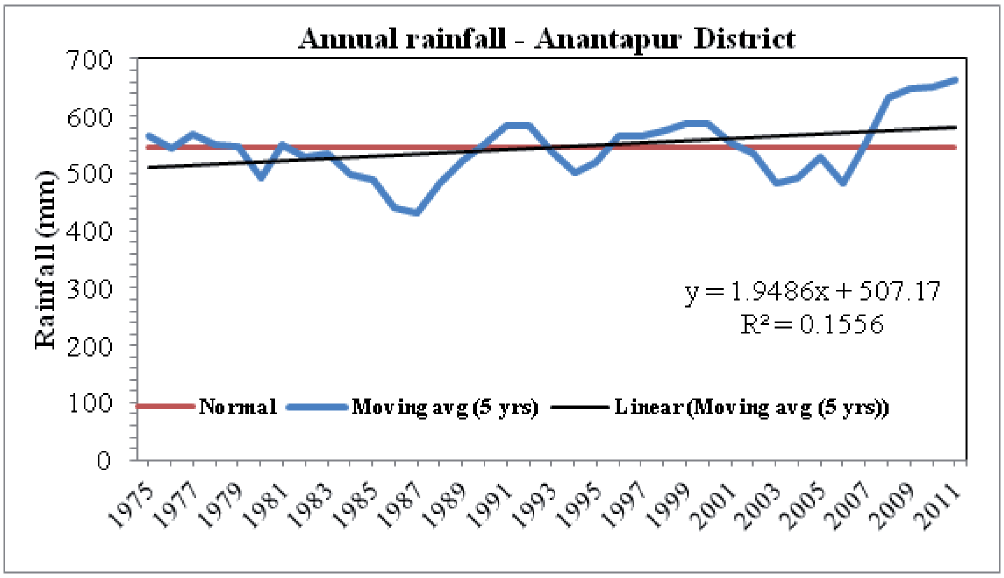
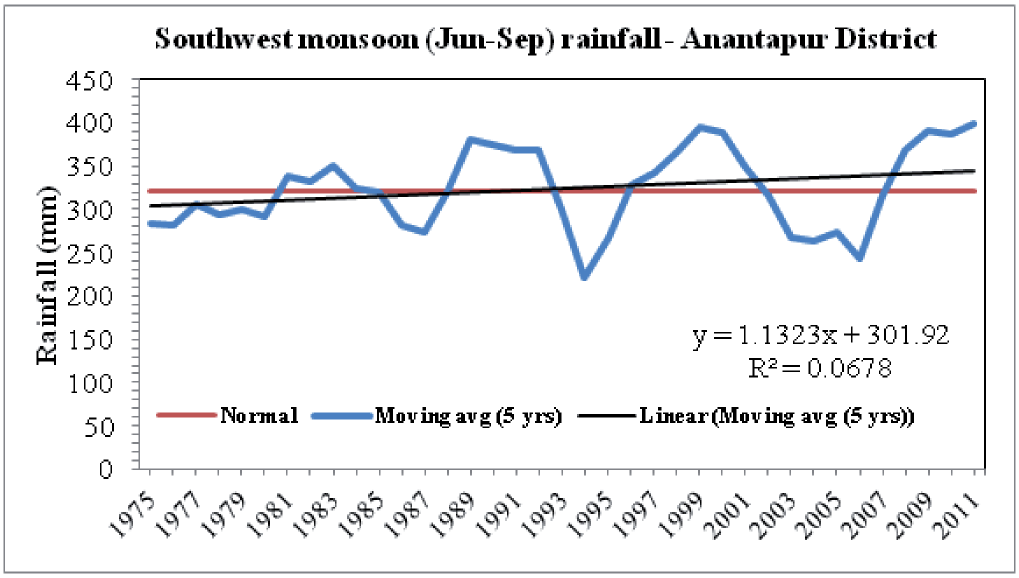


Fig. 141: Normal rainfall during the month of December in different *mandals* of Anantapur district





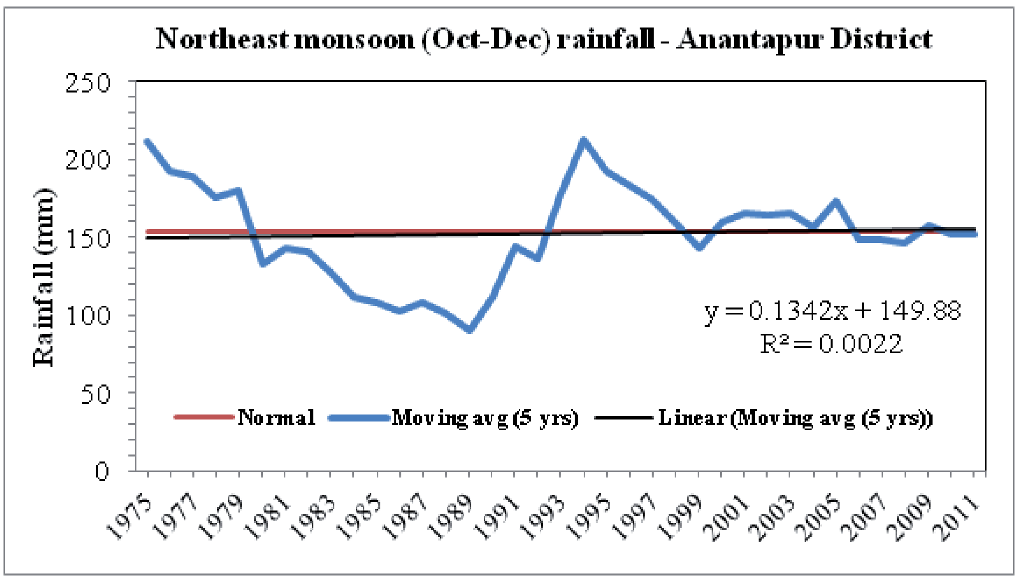
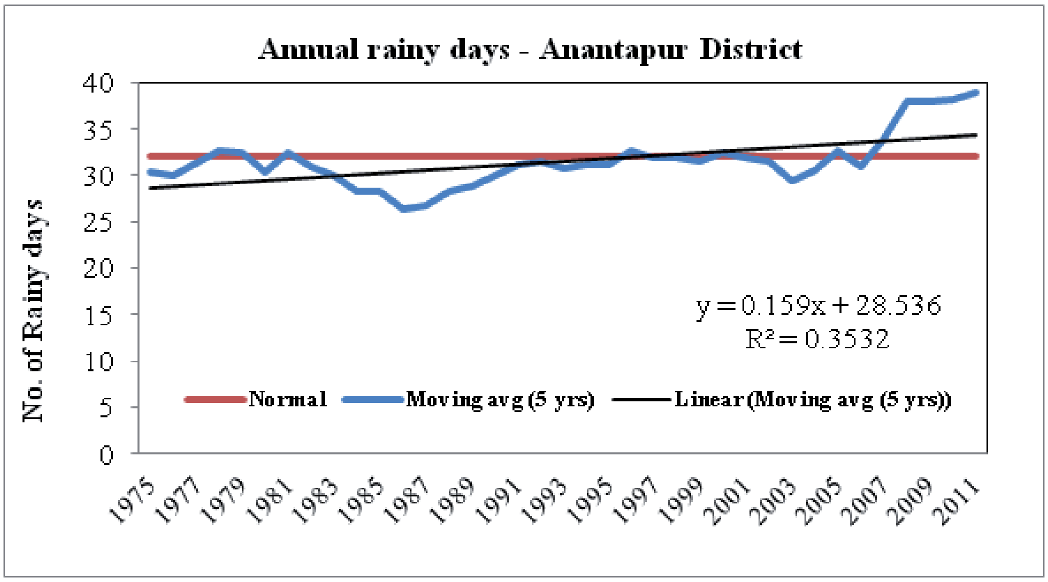
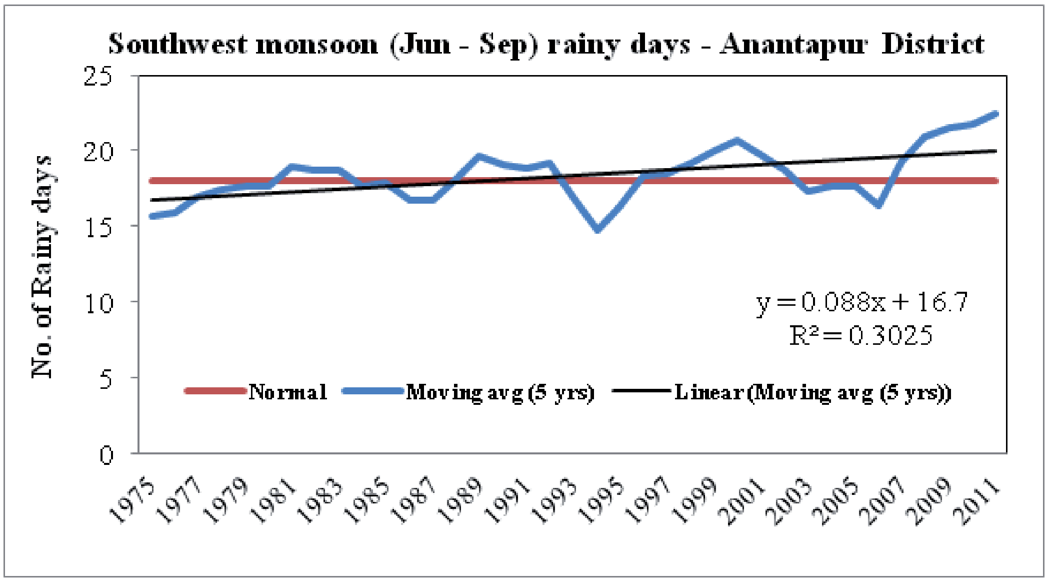


Fig. 142: Variability in annual, Southwest and Northeast monsoon seasonal rainfall in Anantapur district (5-year moving average)





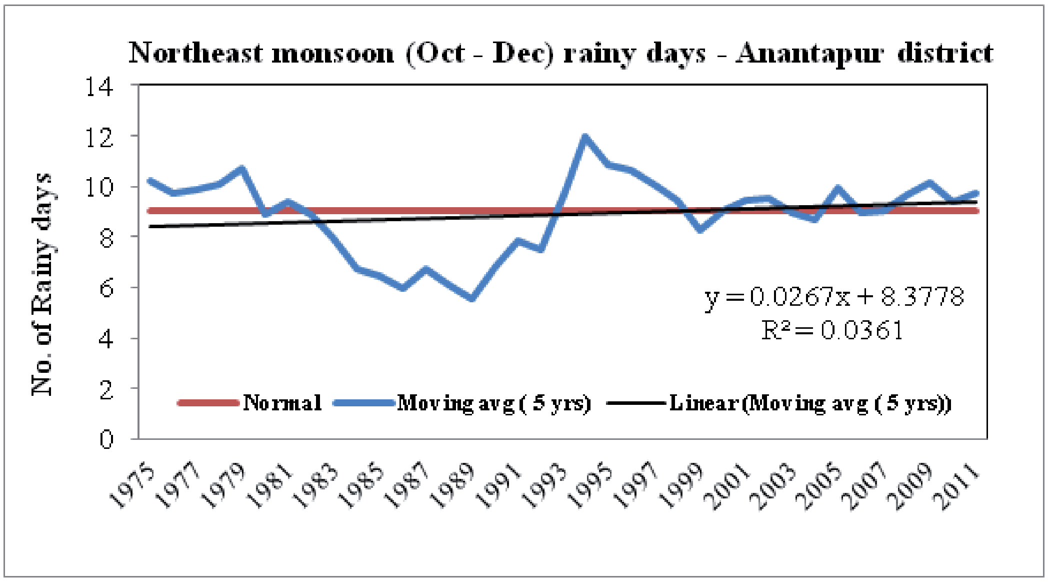


Fig. 143: Variability of rainy days in Annual, Southwest and Northeast monsoon seasons in Anantapur district (5-year moving average)

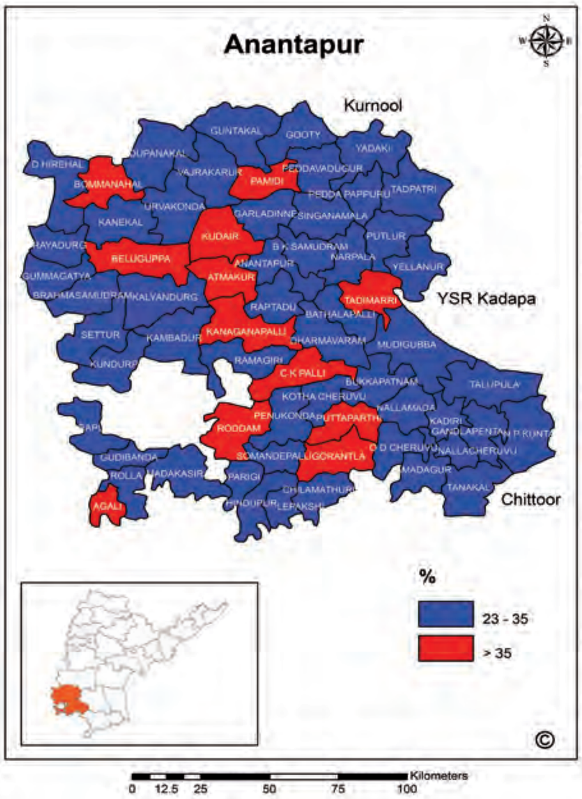


Fig. 144a: Variability in annual rainfall in Anantapur

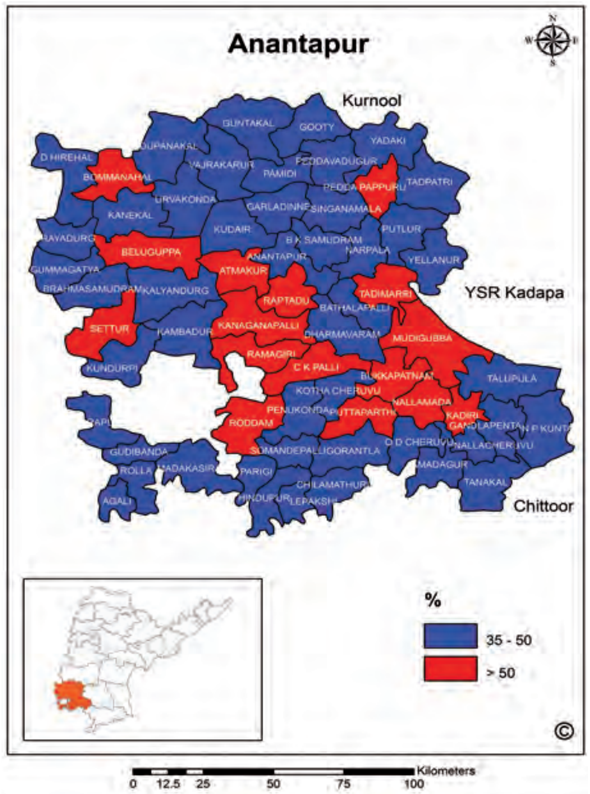


Fig. 144b: Variability in southwest monsoonal rainfall in Anantapur

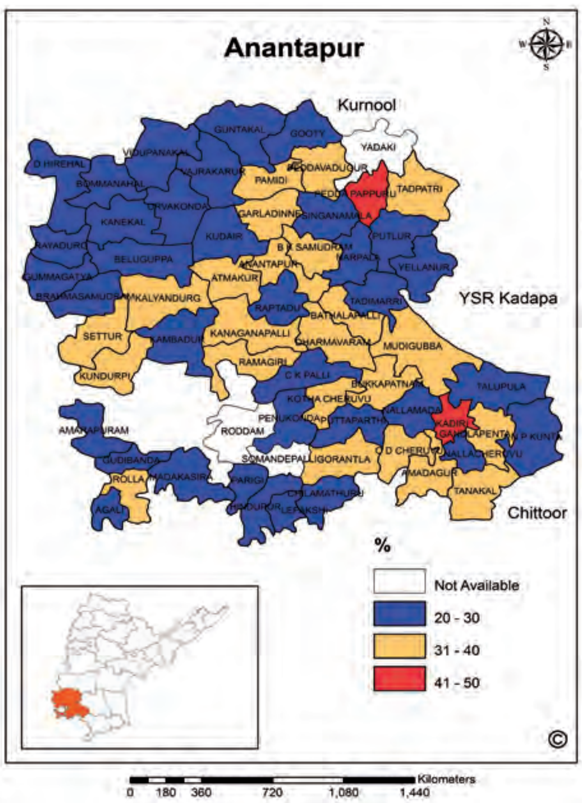


Fig. 145a: Decadal variability in annual rainfall during 1991-2000 decade in Anantapur

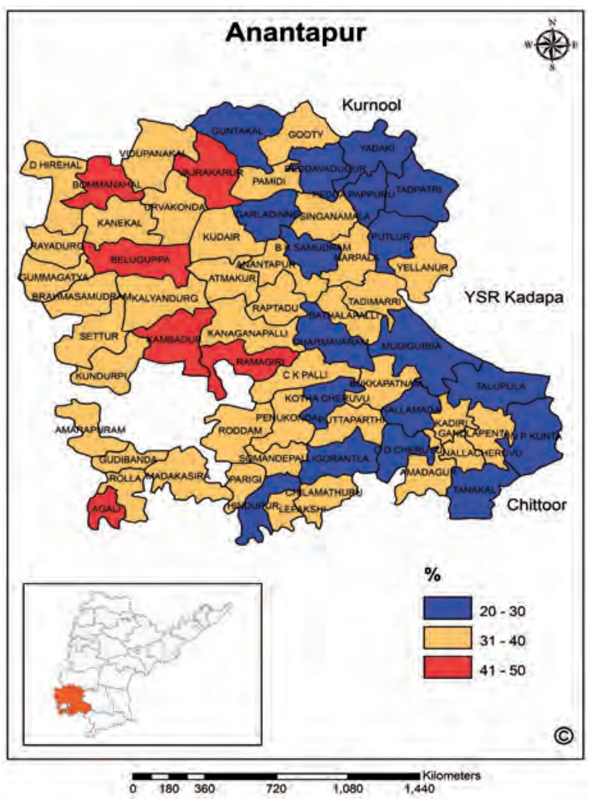


Fig. 145b: Decadal variability in annual rainfall during 2001-2010 decade in Anantapur

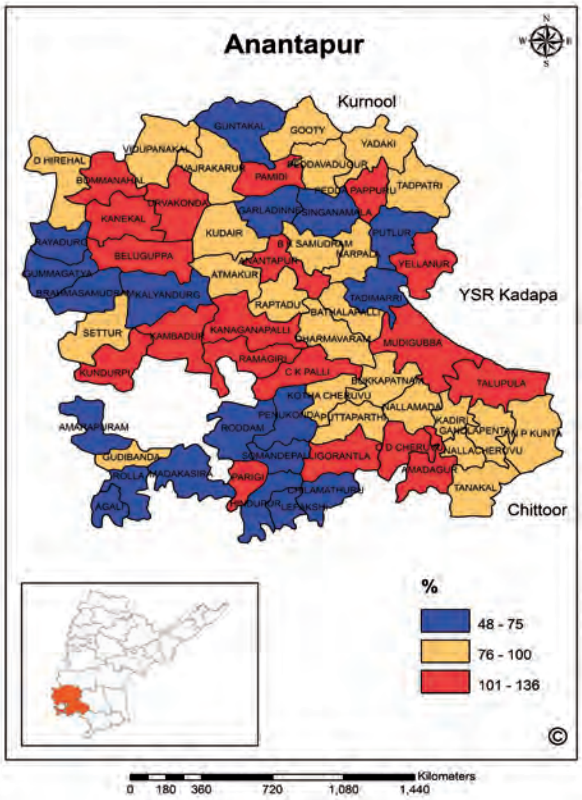


Fig. 146a: Decadal variability in rainfall during the month of June for 1991-2000 decade in Anantapur

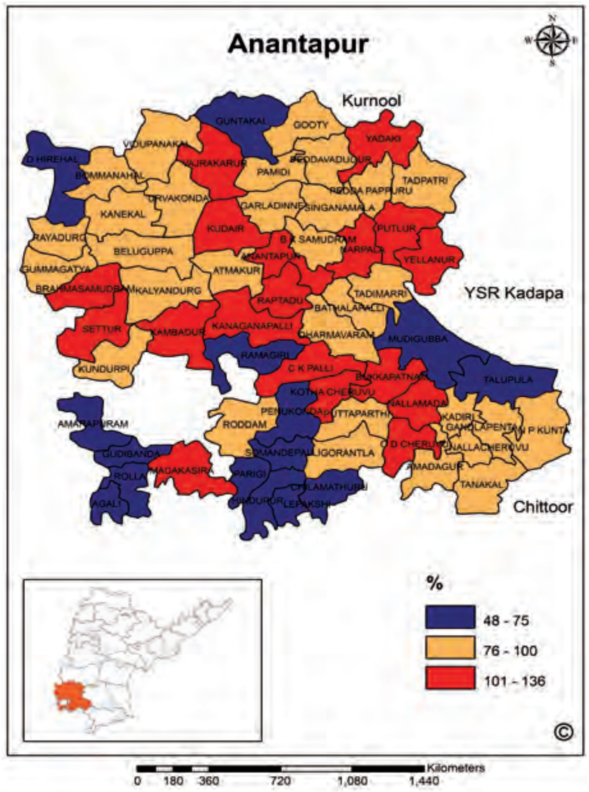


Fig. 146b: Decadal variability in rainfall during the month of June for 2001-2010 decade in Anantapur

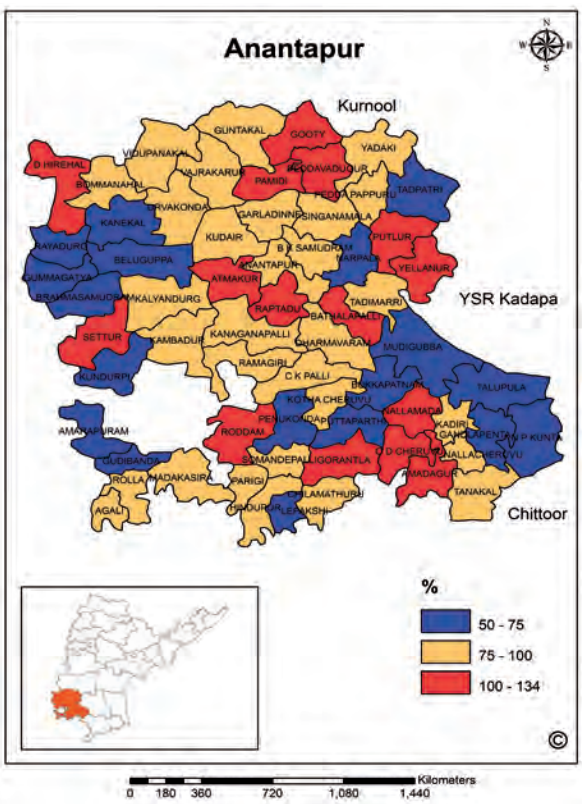


Fig. 147a: Decadal variability in rainfall during the month of July for 1991-2000 decade in Anantapur

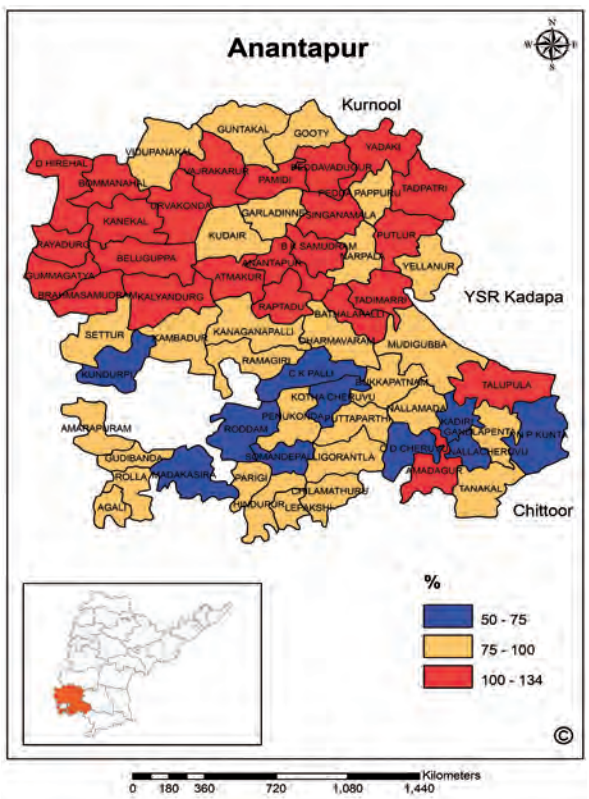


Fig. 147b: Decadal variability in rainfall during the month of July for 2001-2010 decade in Anantapur

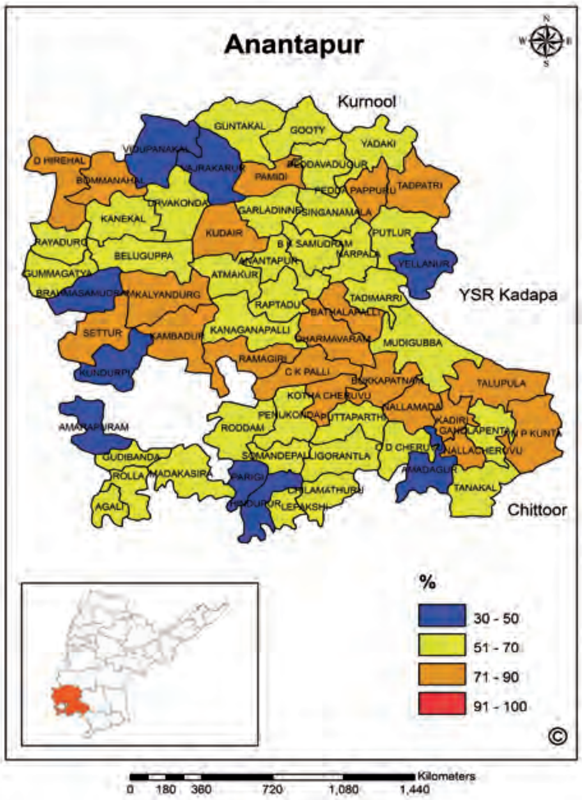


Fig. 148a: Decadal variability in rainfall during the month of September for 1991-2000 decade in Anantapur

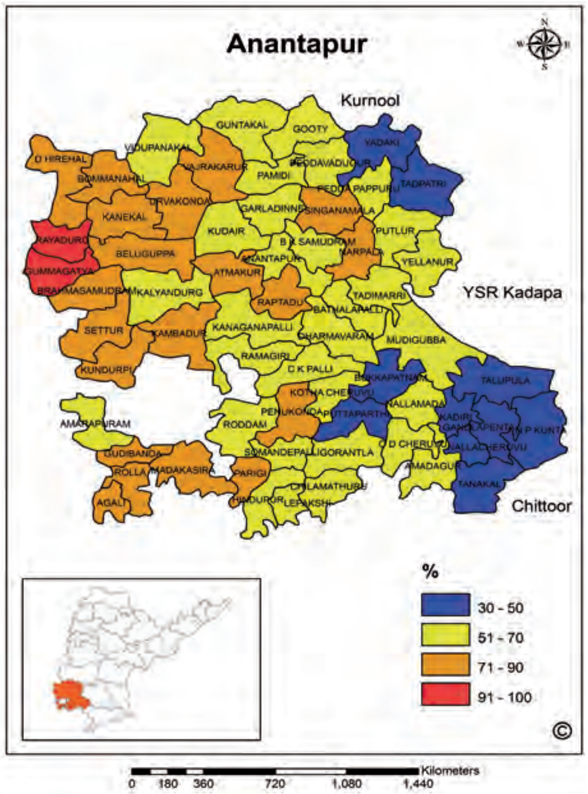


Fig. 148b: Decadal variability in rainfall during the month of September for 2001-2010 decade in Anantapur

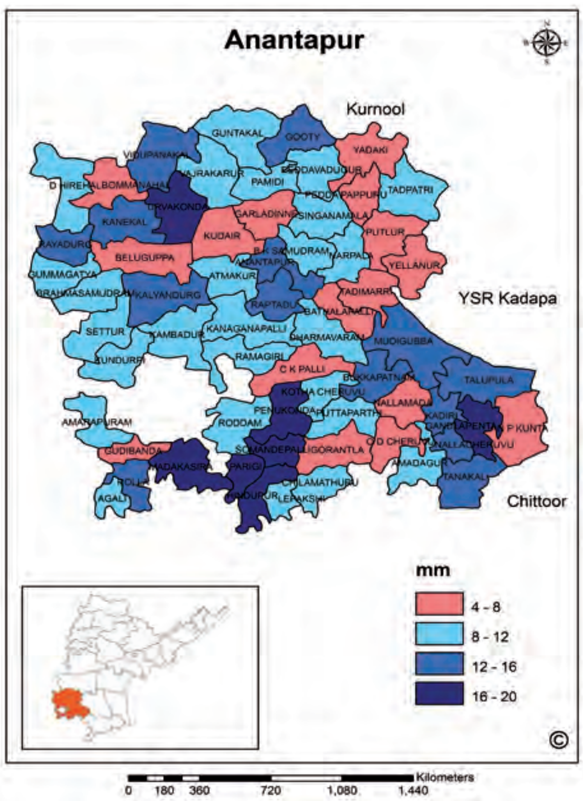


Fig. 149: Dependable rainfall (75% probability) during May month in different *mandals* of Anantapur district

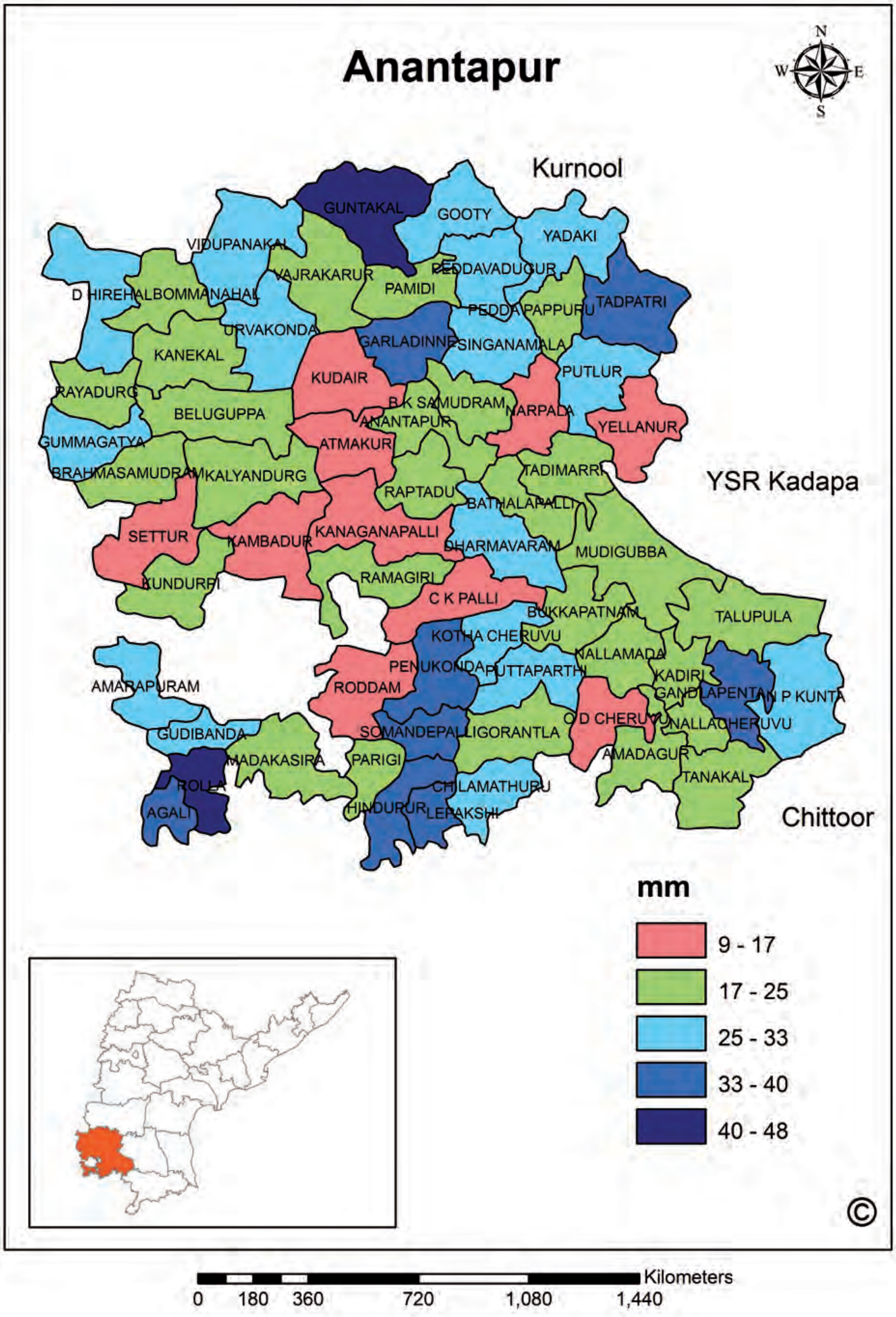


Fig. 150: Dependable rainfall (75% probability) during June month in different *mandals* of Anantapur district

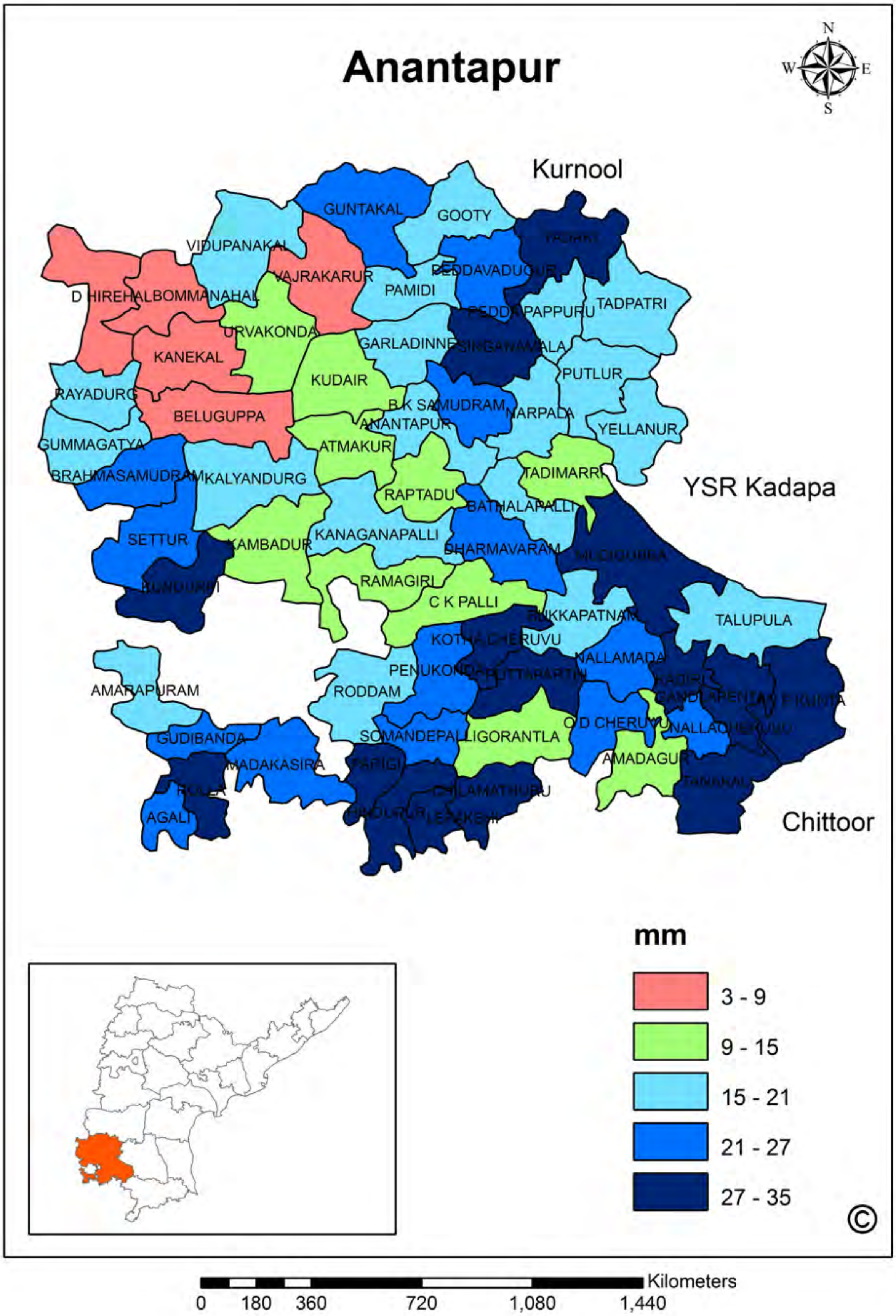


Fig. 151: Dependable rainfall (75% probability) during July month in different *mandals* of Anantapur district

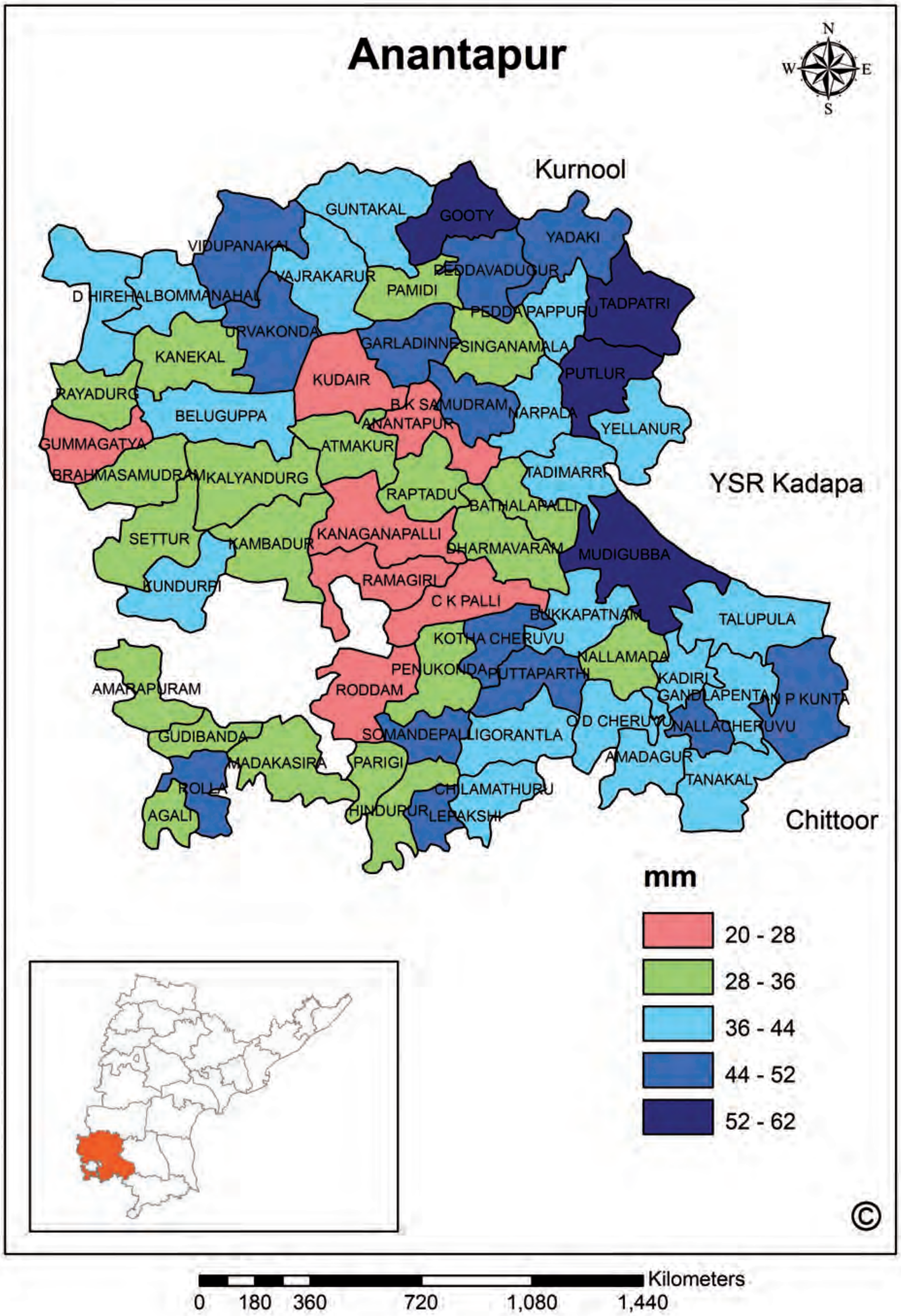


Fig. 152: Dependable rainfall (75% probability) during August month in different *mandals* of Anantapur district

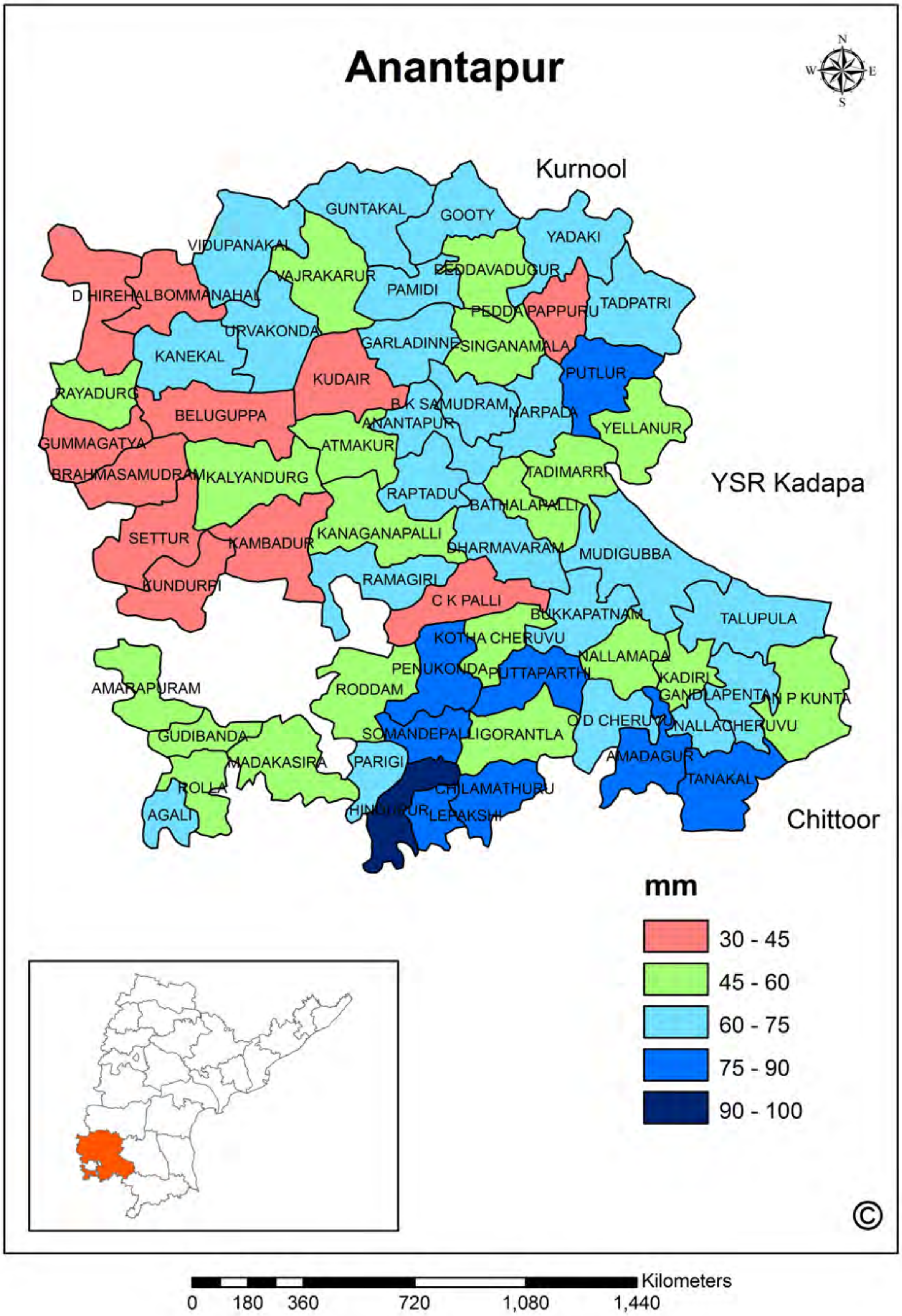


Fig. 153: Dependable rainfall (75% probability) during September month in different *mandals* of Anantapur district

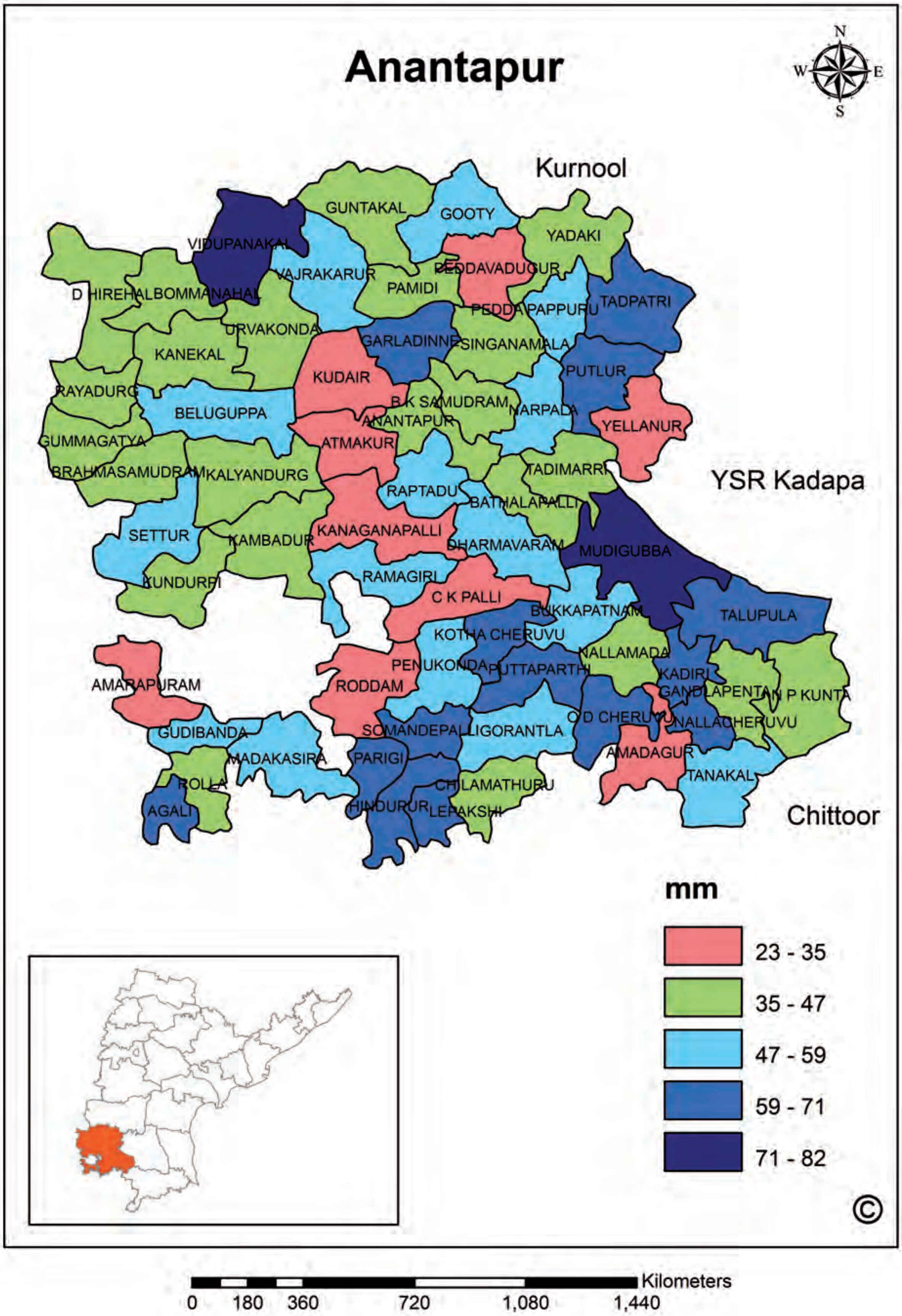


Fig. 154: Dependable rainfall (75% probability) during October month in different *mandals* of Anantapur district

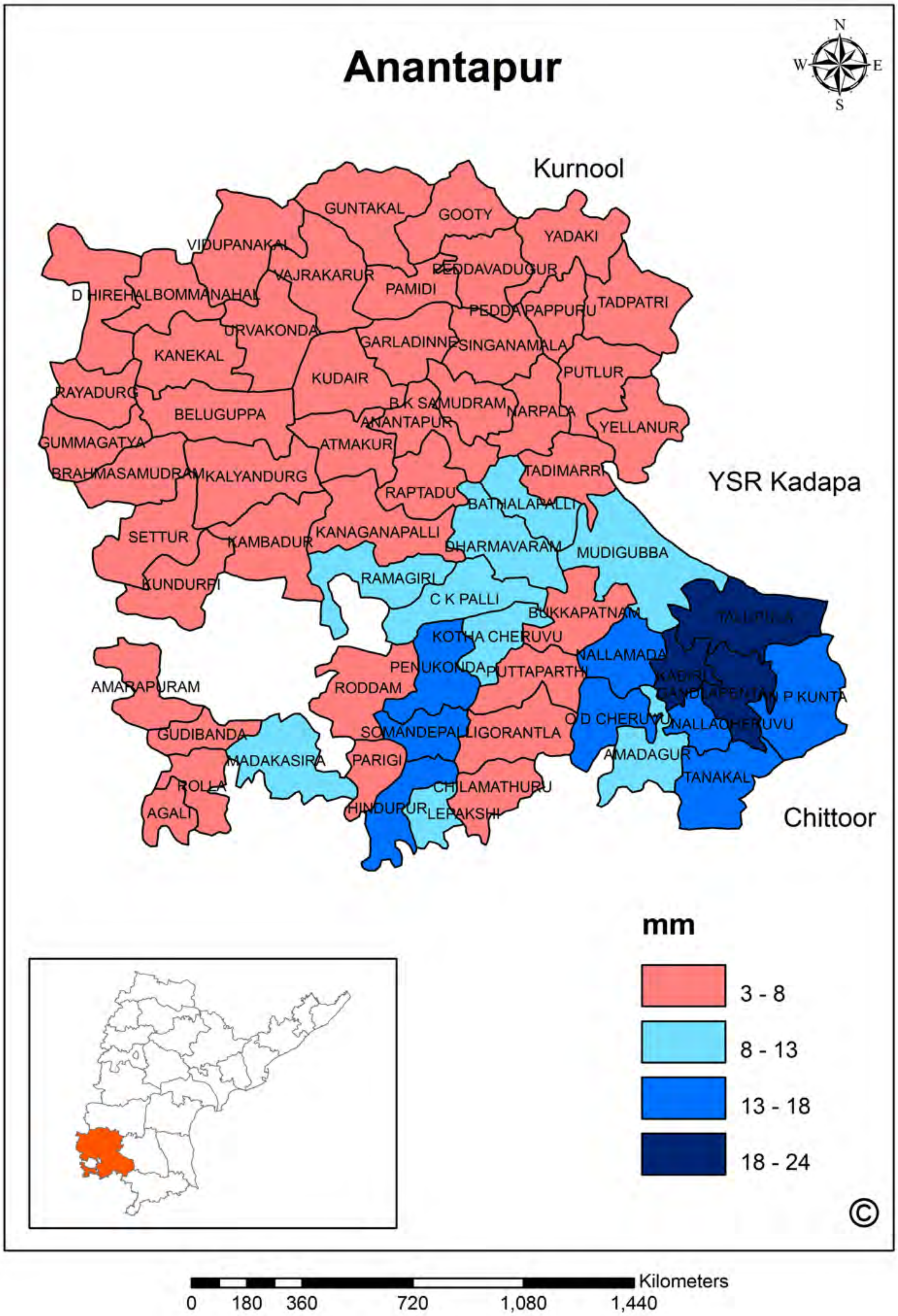


Fig. 155: Dependable rainfall (75% probability) during November month in different *mandals* of Anantapur district

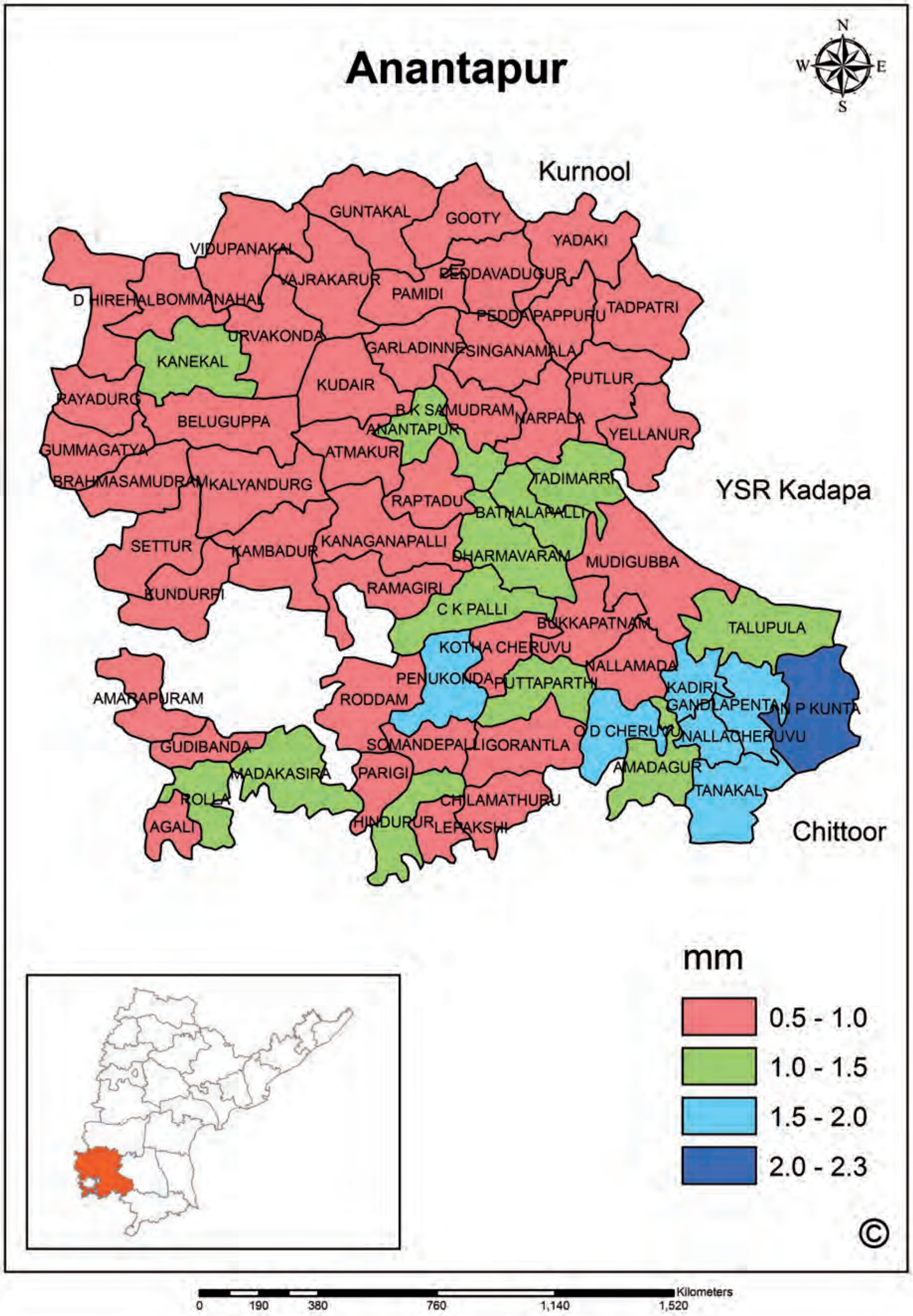


Fig. 156: Dependable rainfall (75% probability) during December month in different *mandals* of Anantapur district

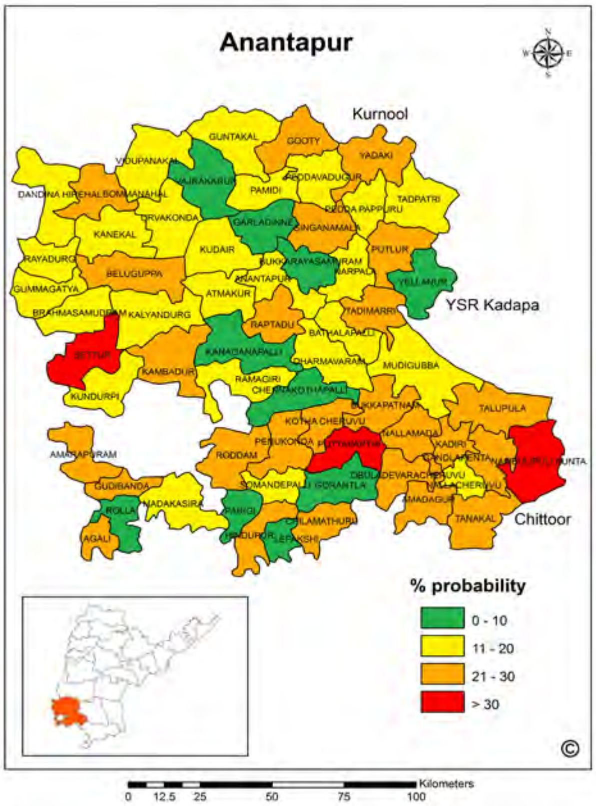


Fig. 157a: Per cent probability of mild meteorological drought in different *mandals* of Anantapur

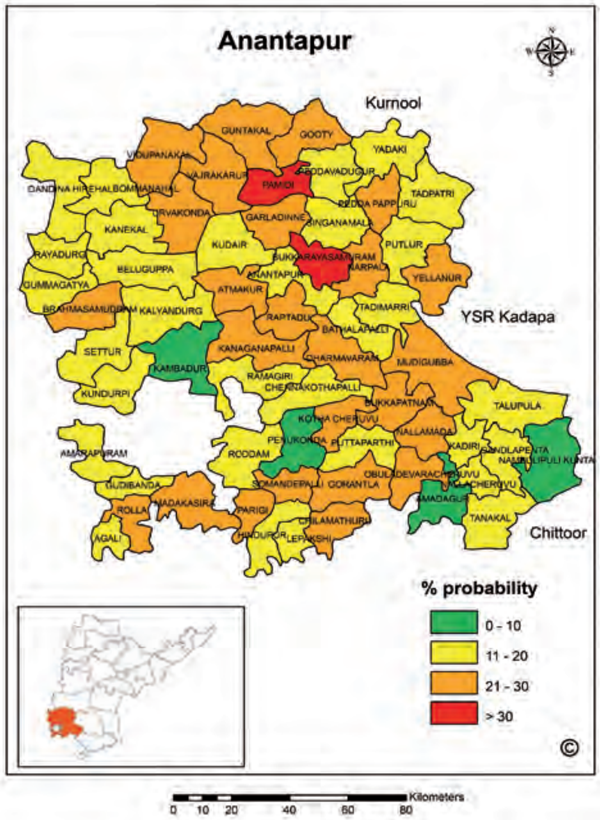


Fig. 157b: Per cent probability of moderate meteorological drought in different *mandals* of Anantapur

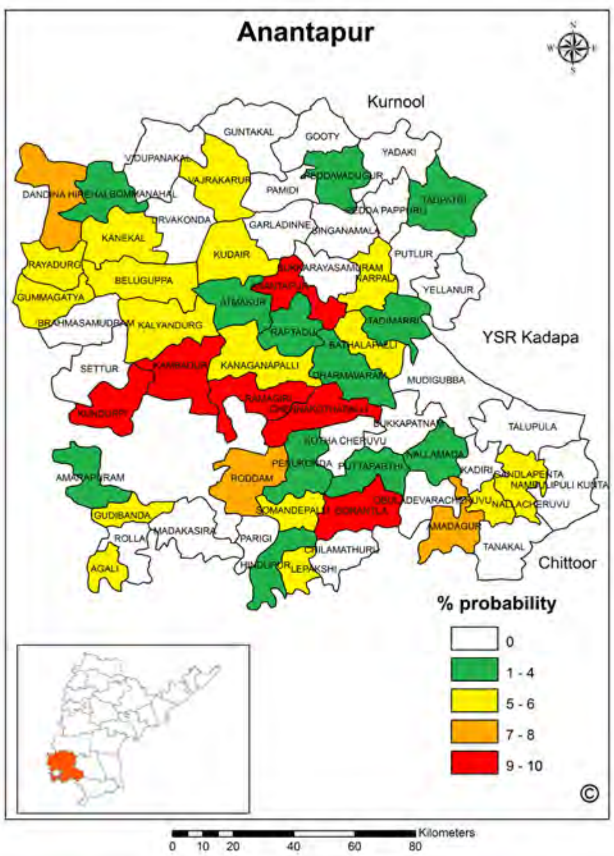


Fig. 157c: Per cent probability of severe meteorological drought in different *mandals* of Anantapur

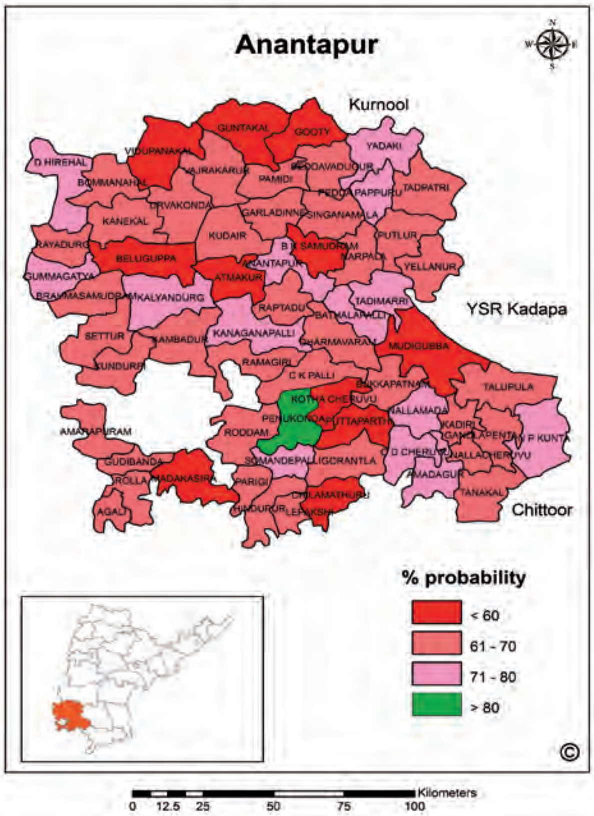


Fig. 158a: Probabilities for near normal rainfall conditions on annual basis in Anantapur district

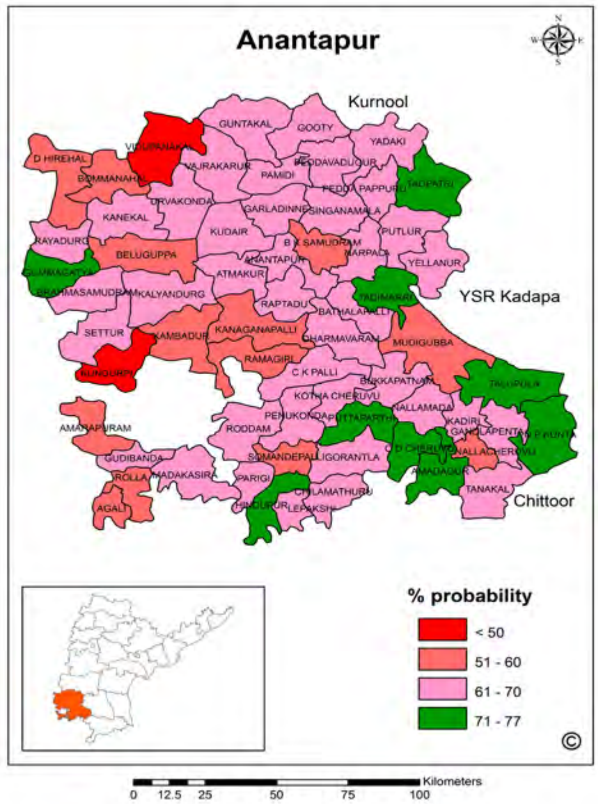


Fig. 158b: Probabilities for near normal rainfall conditions during SWM season in Anantapur district

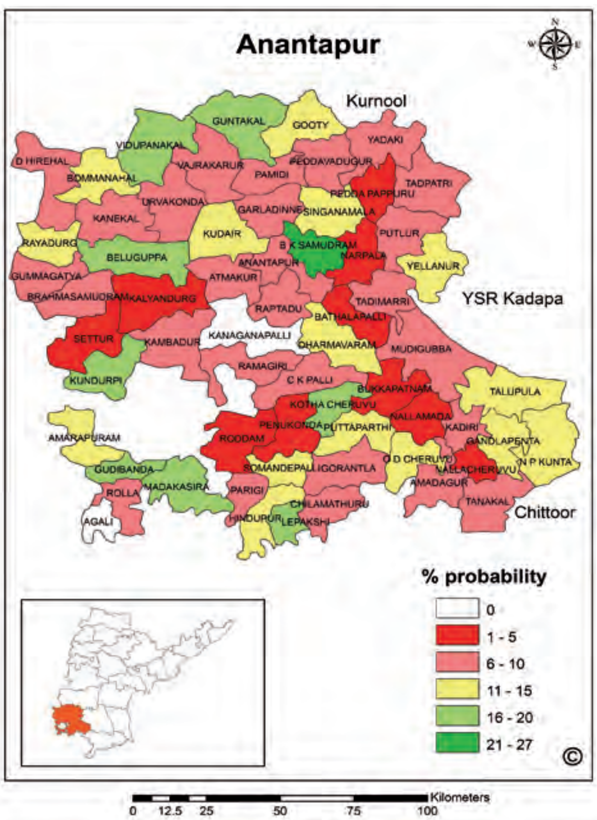


Fig. 159a: Probabilities for moderately wet events on annual basis in Anantapur district

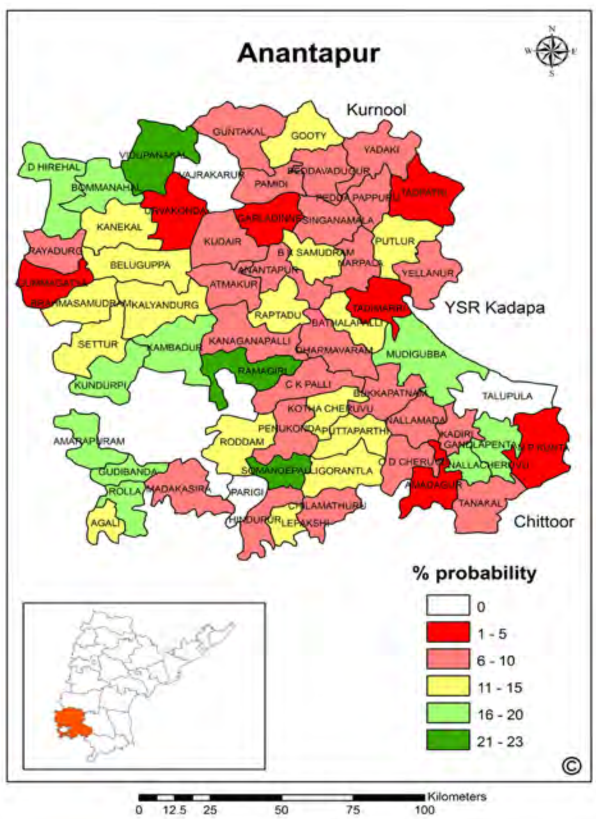


Fig. 159b: Probabilities for moderately wet events during SWM season in Anantapur district

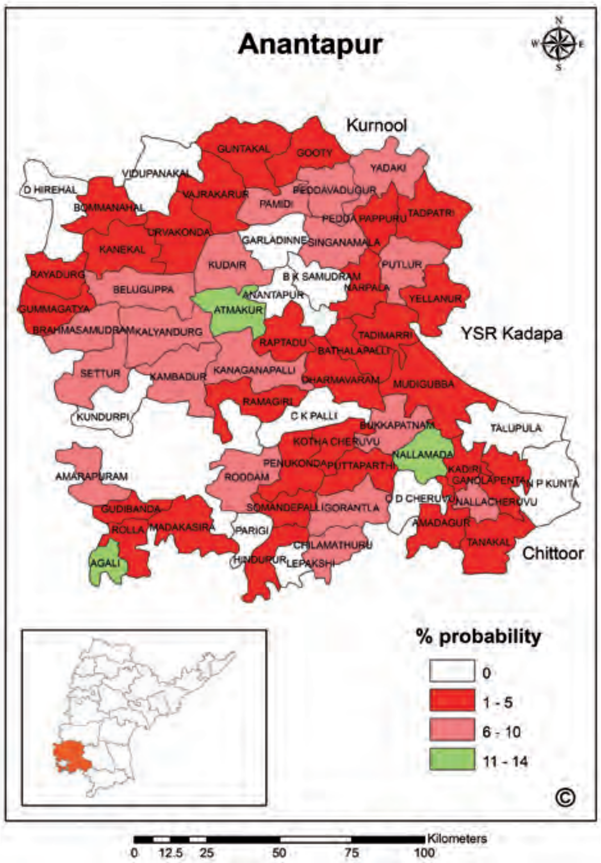


Fig. 160a: Probabilities for very wet events on annual basis in Anantapur district

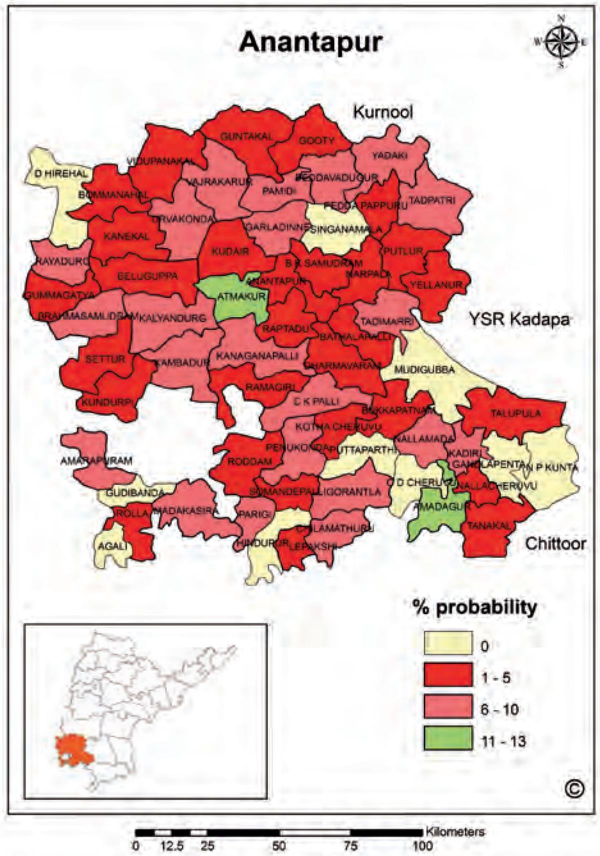


Fig. 160b: Probabilities for very wet events during SWM season in Anantapur district

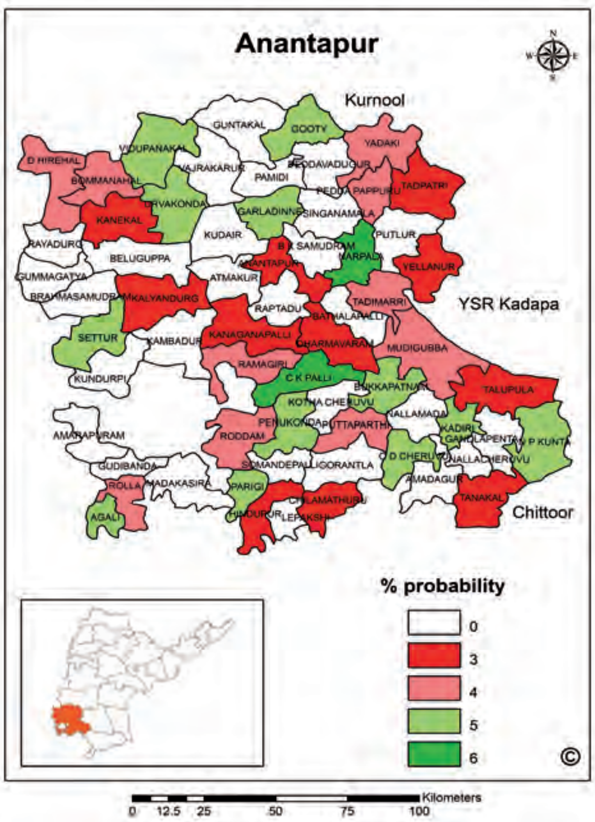


Fig. 161a: Probabilities for extremely wet events on annual basis in Anantapur district

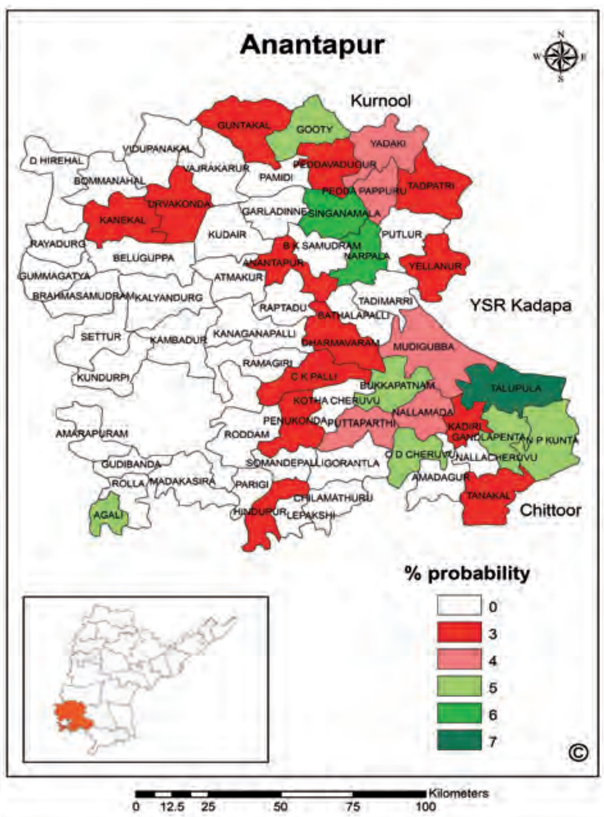


Fig. 161b: Probabilities for extremely wet events during SWM season in Anantapur district

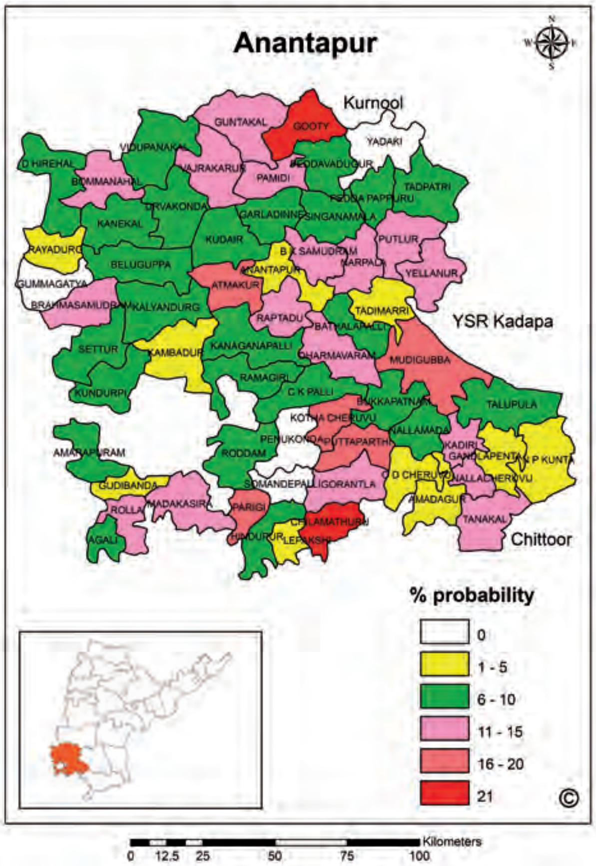


Fig. 162a: Probabilities for moderately dry conditions on annual basis in Anantapur district

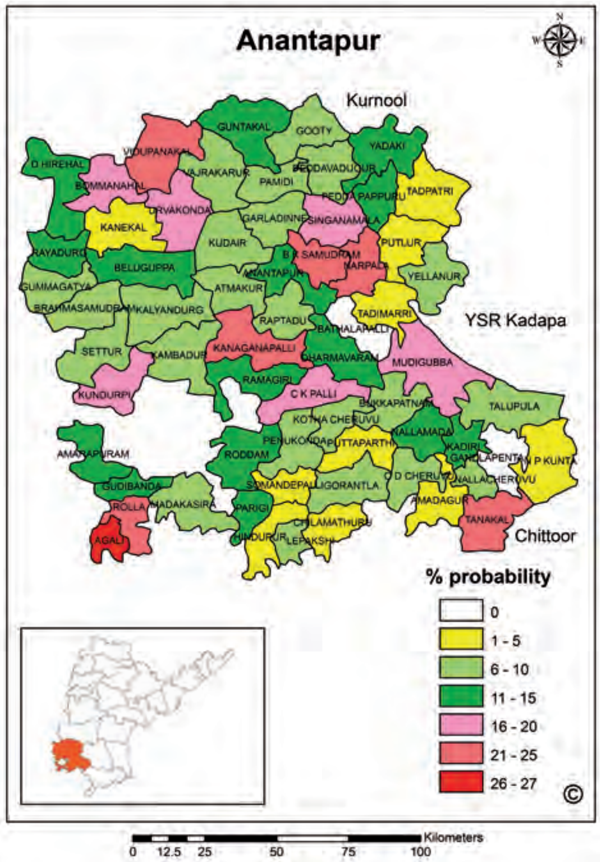


Fig. 162b: Probabilities for moderately dry conditions during SWM season in Anantapur district

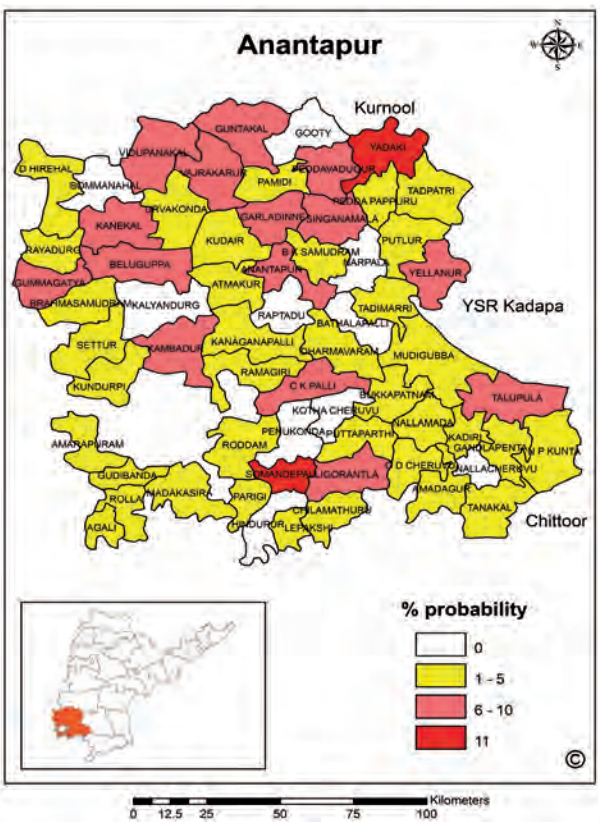


Fig. 163a: Probabilities of severely dry conditions on annual basis in Anantapur district

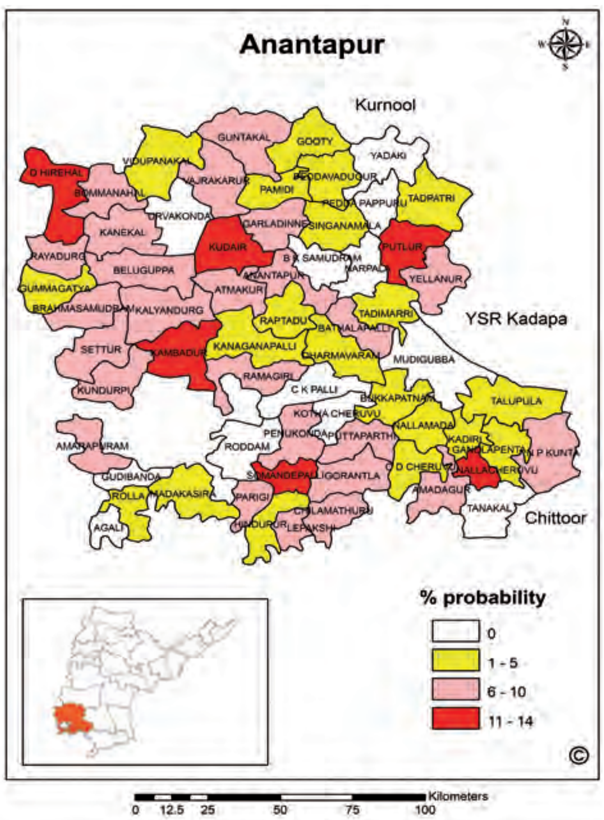


Fig. 163b: Probabilities of severely dry conditions during SWM season in Anantapur district

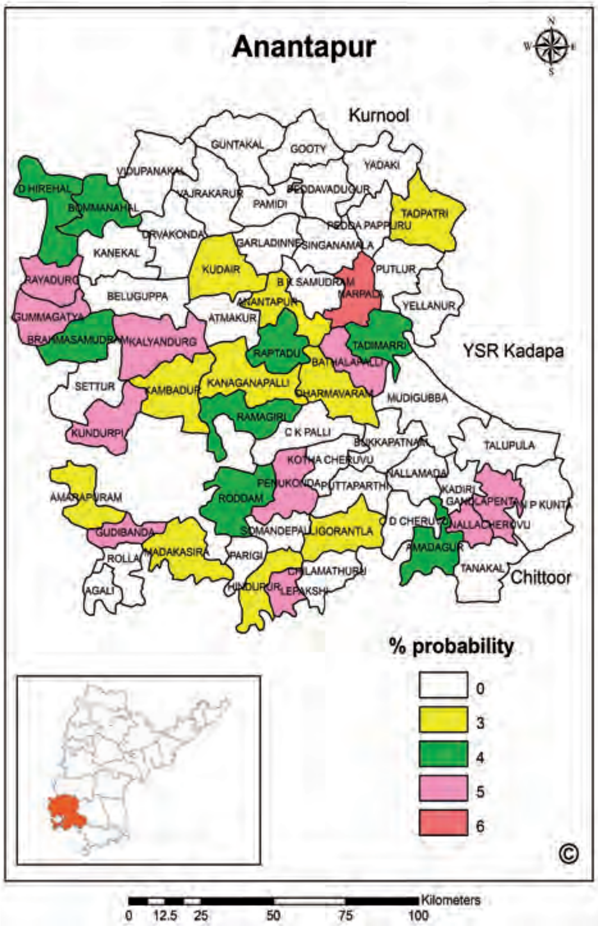


Fig. 164a: Probabilities of extremely dry conditions on annual basis in Anantapur district

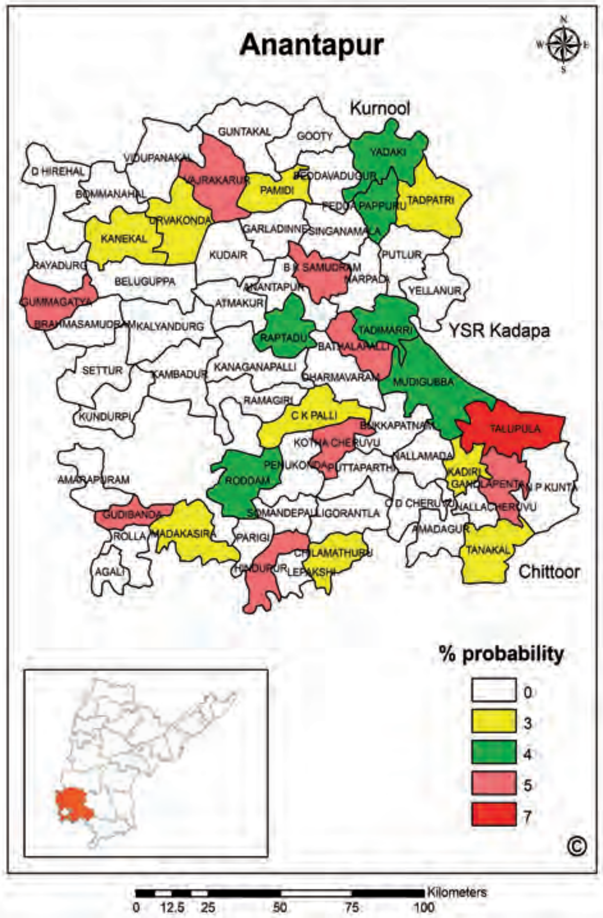


Fig. 164b: Probabilities of extremely dry conditions during SWM season in Anantapur district

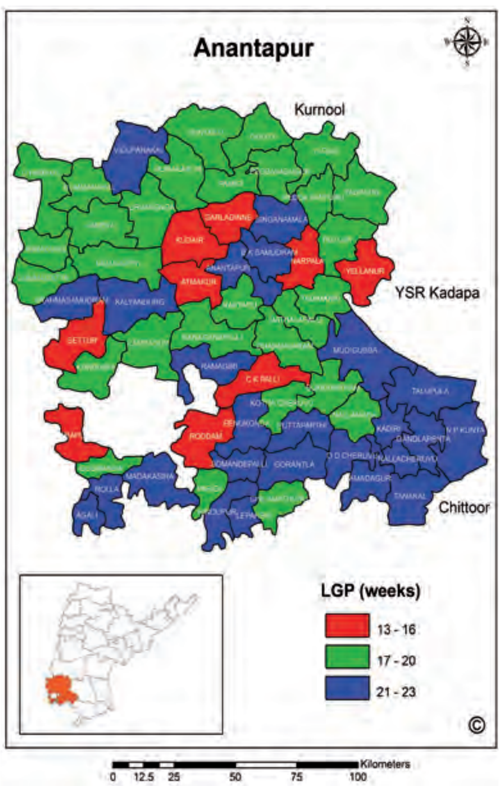


Fig. 165: Length of growing period across different *mandals* of Anantapur district

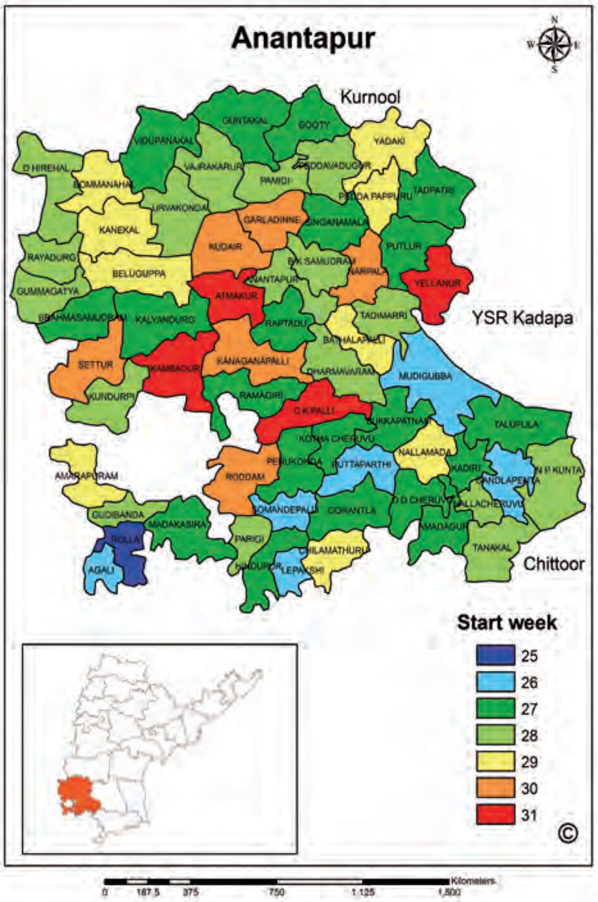


Fig. 166a: Average week of start of growing period in different *mandals* of Anantapur

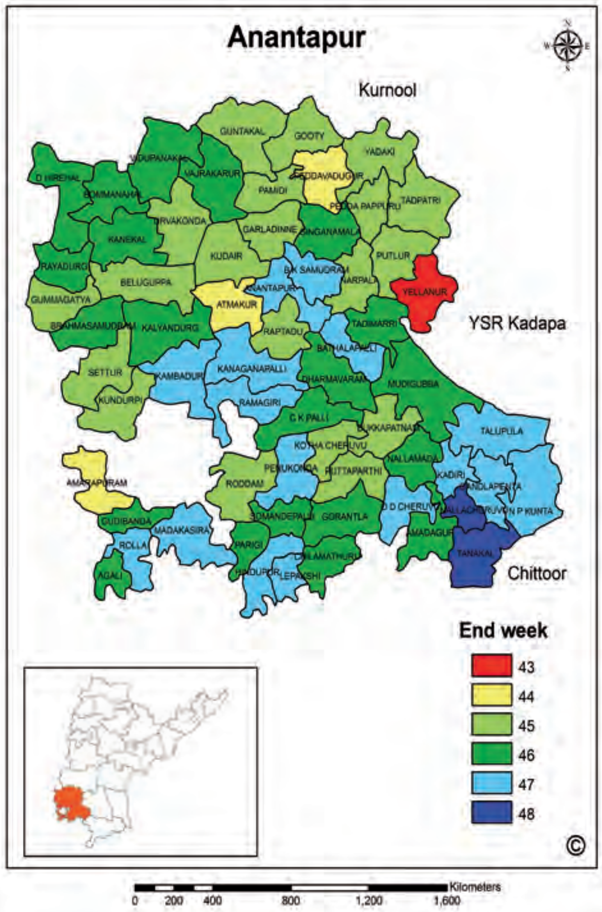


Fig. 166b: Average week of end of growing period in different *mandals* of Anantapur

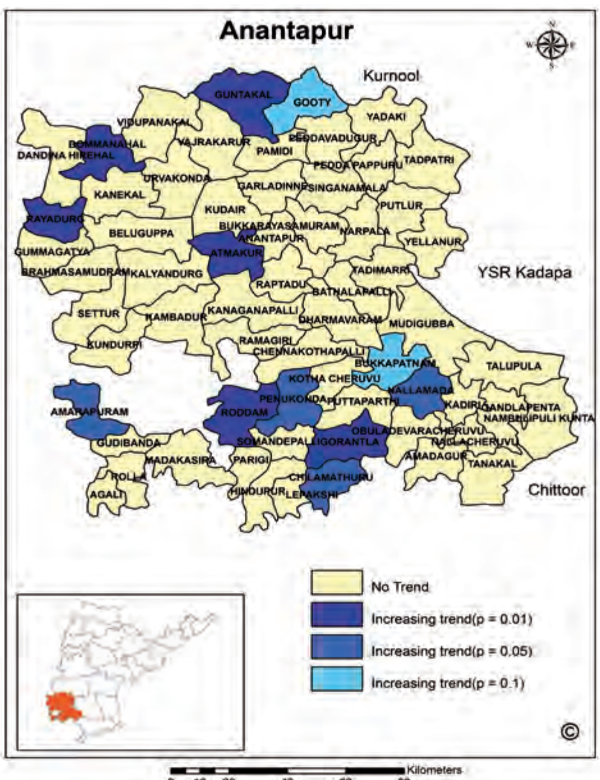


Fig. 167a: Spatial distribution of *mandals* showing trends in annual rainfall

Fig. 167b: Spatial distribution of *mandals* showing trends in southwest monsoon rainfall

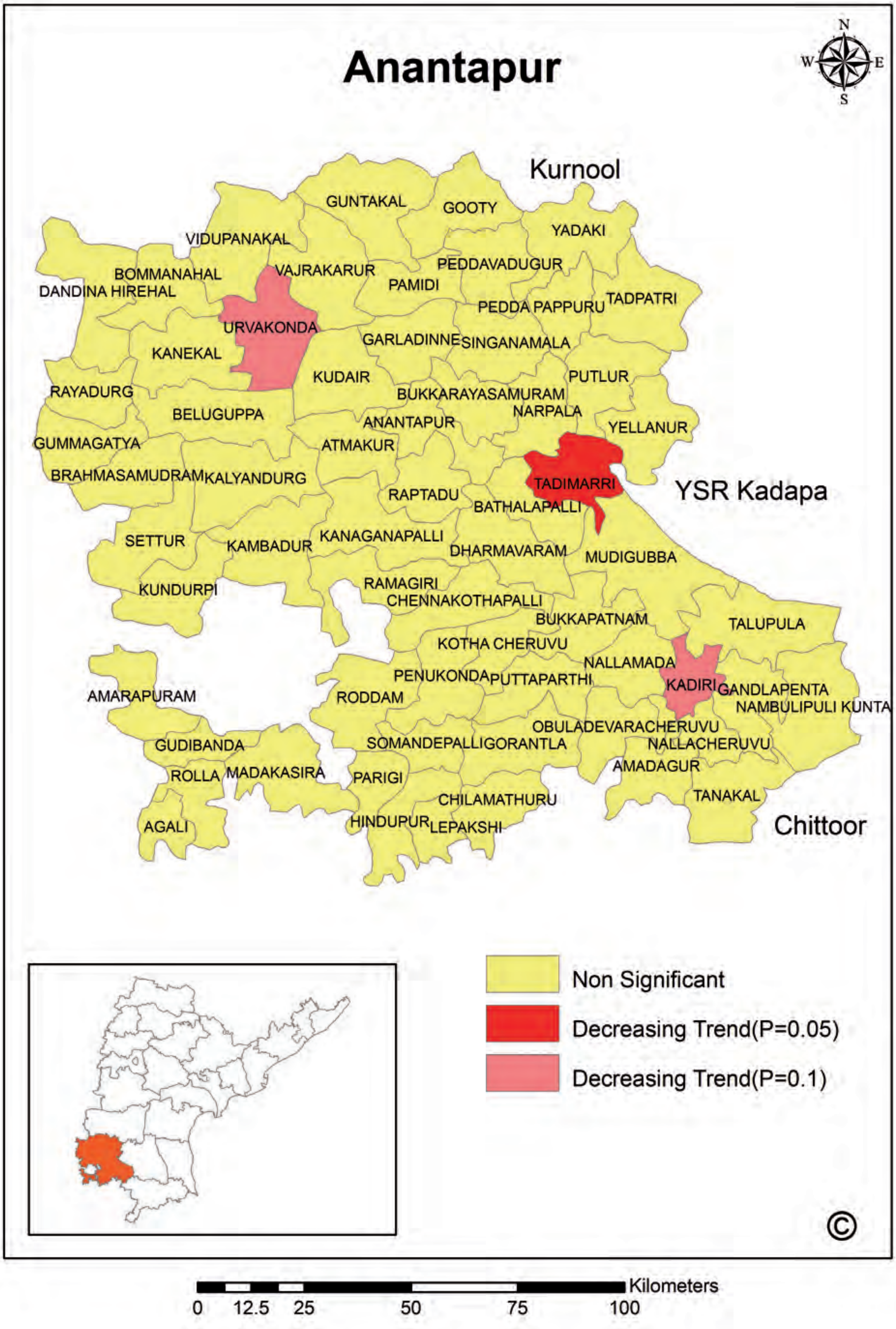


Fig. 168: Spatial distribution of *mandals* showing trends in annual (75-100 mm category) rainfall

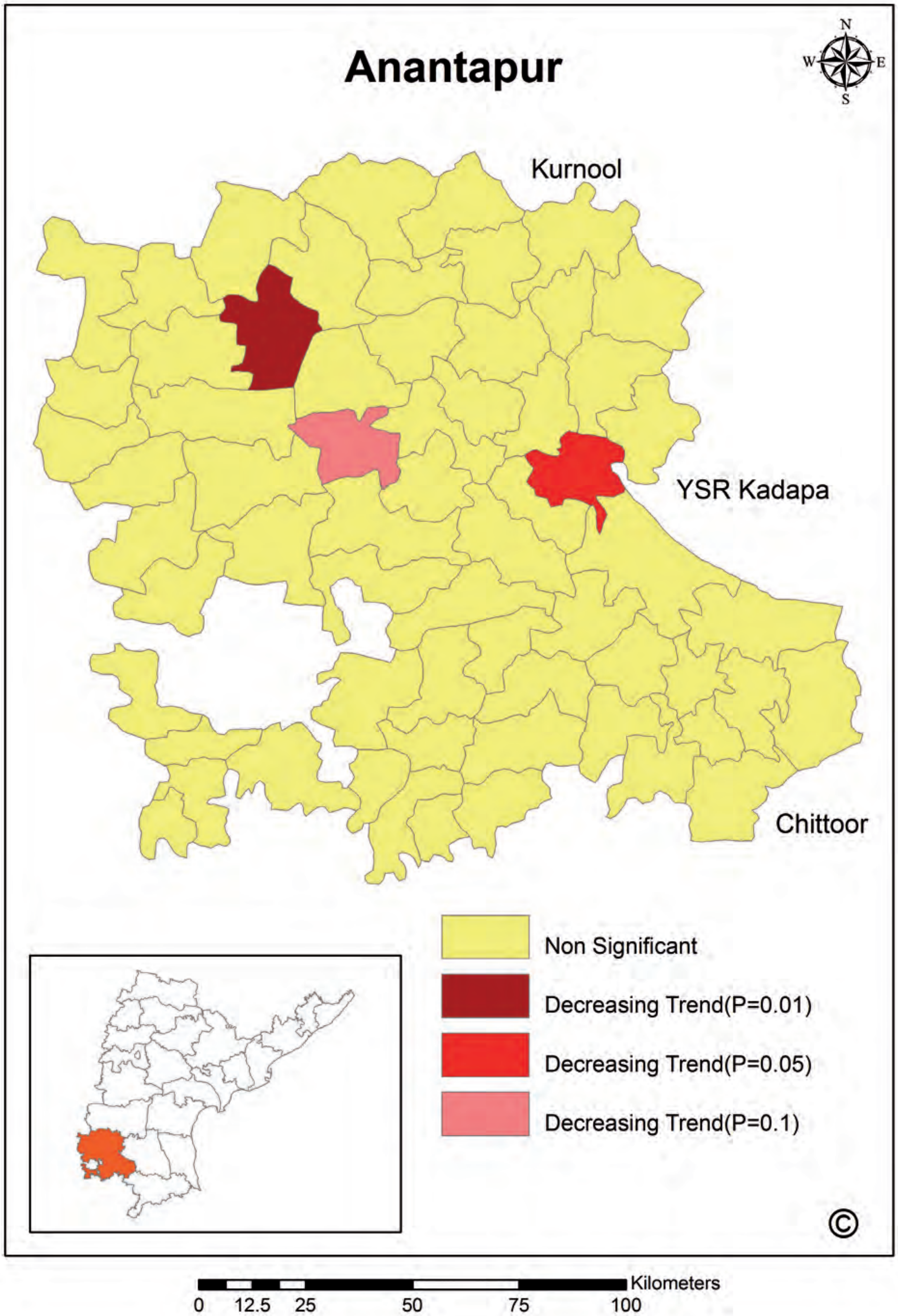


Fig. 169: Spatial distribution of *mandals* showing trends in Southwest monsoon (75-100 mm category) rainfall

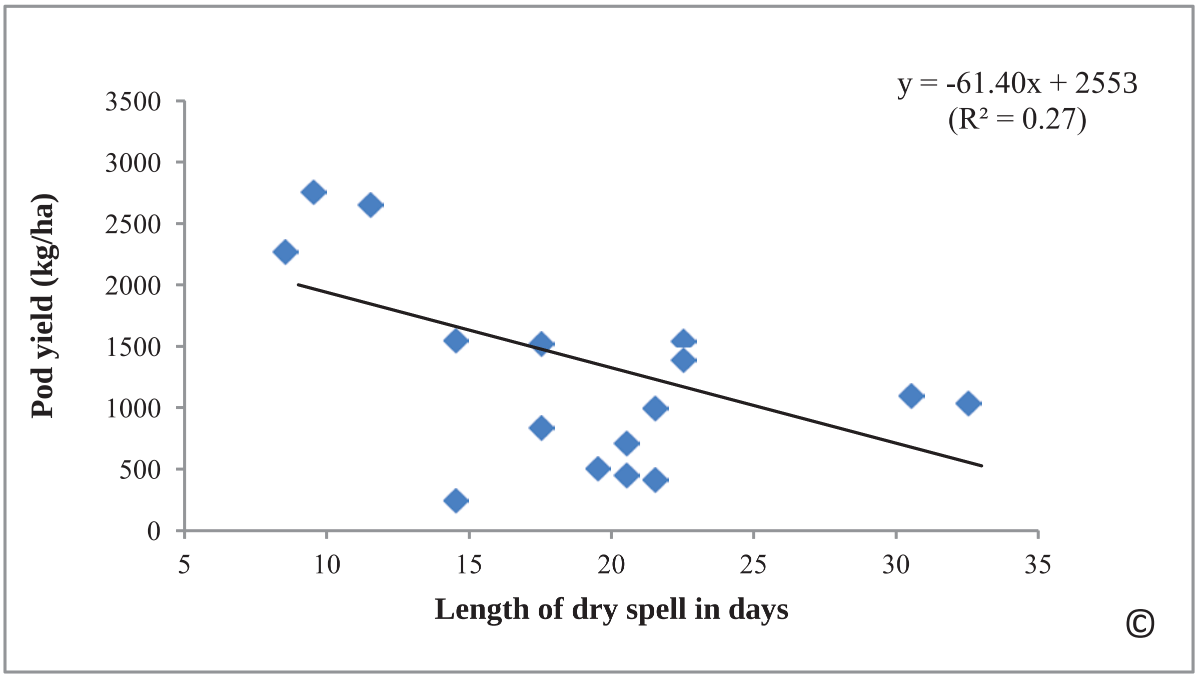


Fig. 170: Influence of length of dry spell during 0-30 ± 5 DAS on groundnut yields at Anantapur

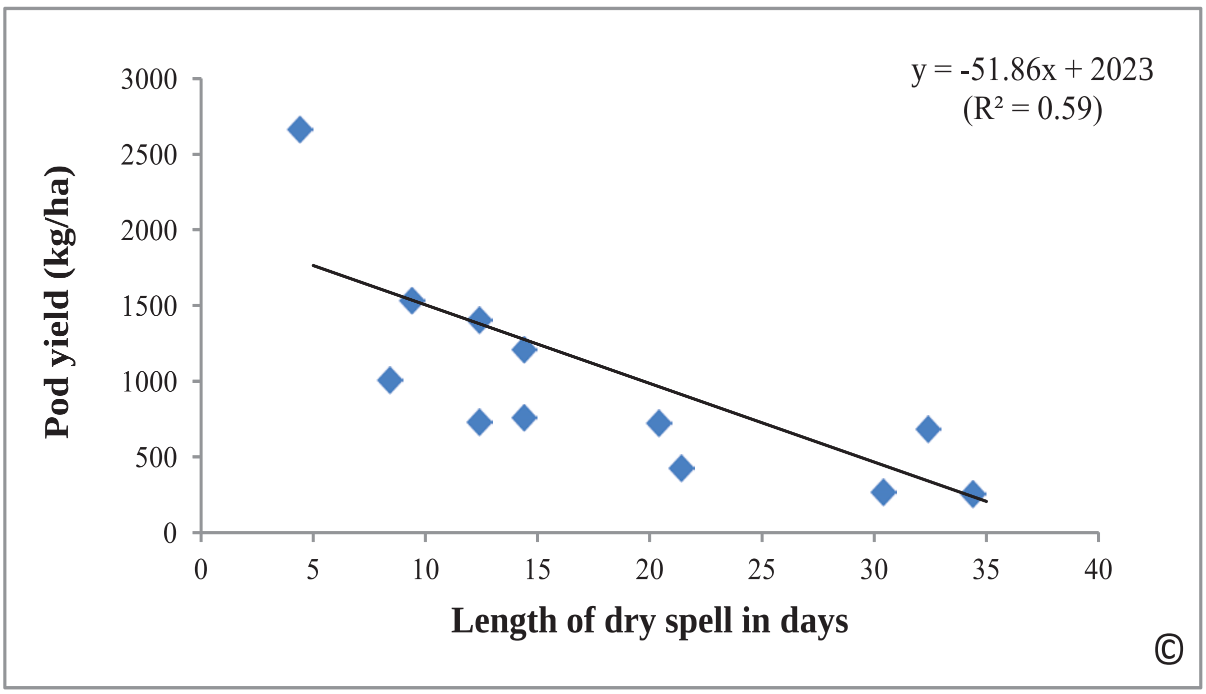


Fig. 171: Influence of length of dry spell during 51-80 ± 5 DAS on groundnut yields at Anantapur

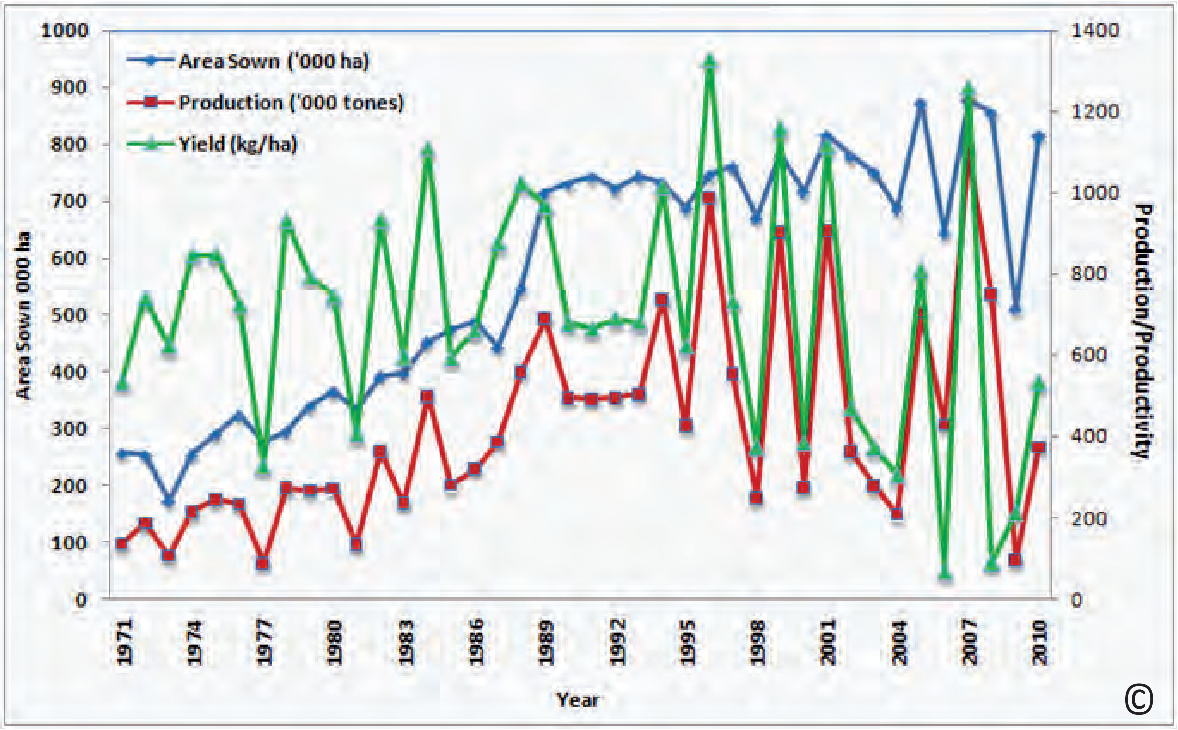


Fig. 172: Trend analysis of area, production and productivity of groundnut in Anantapur district

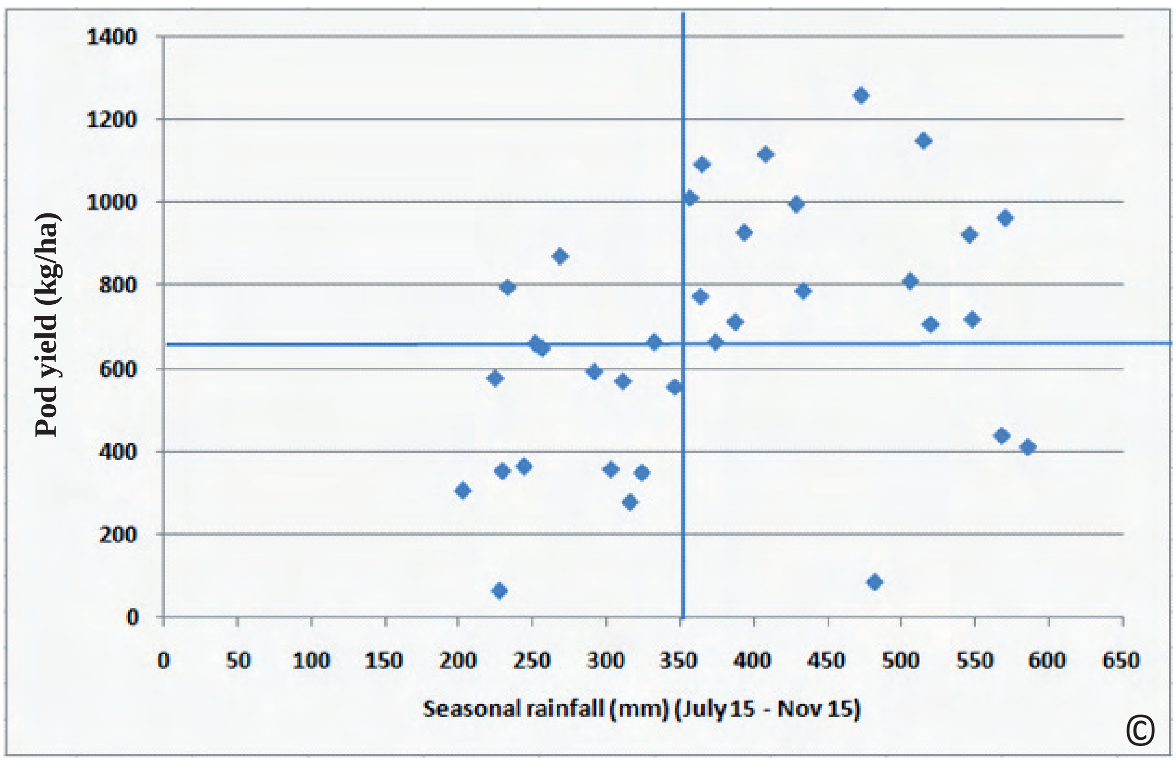


Fig 173: Groundnut yields in Anantapur district as influenced by seasonal rainfall

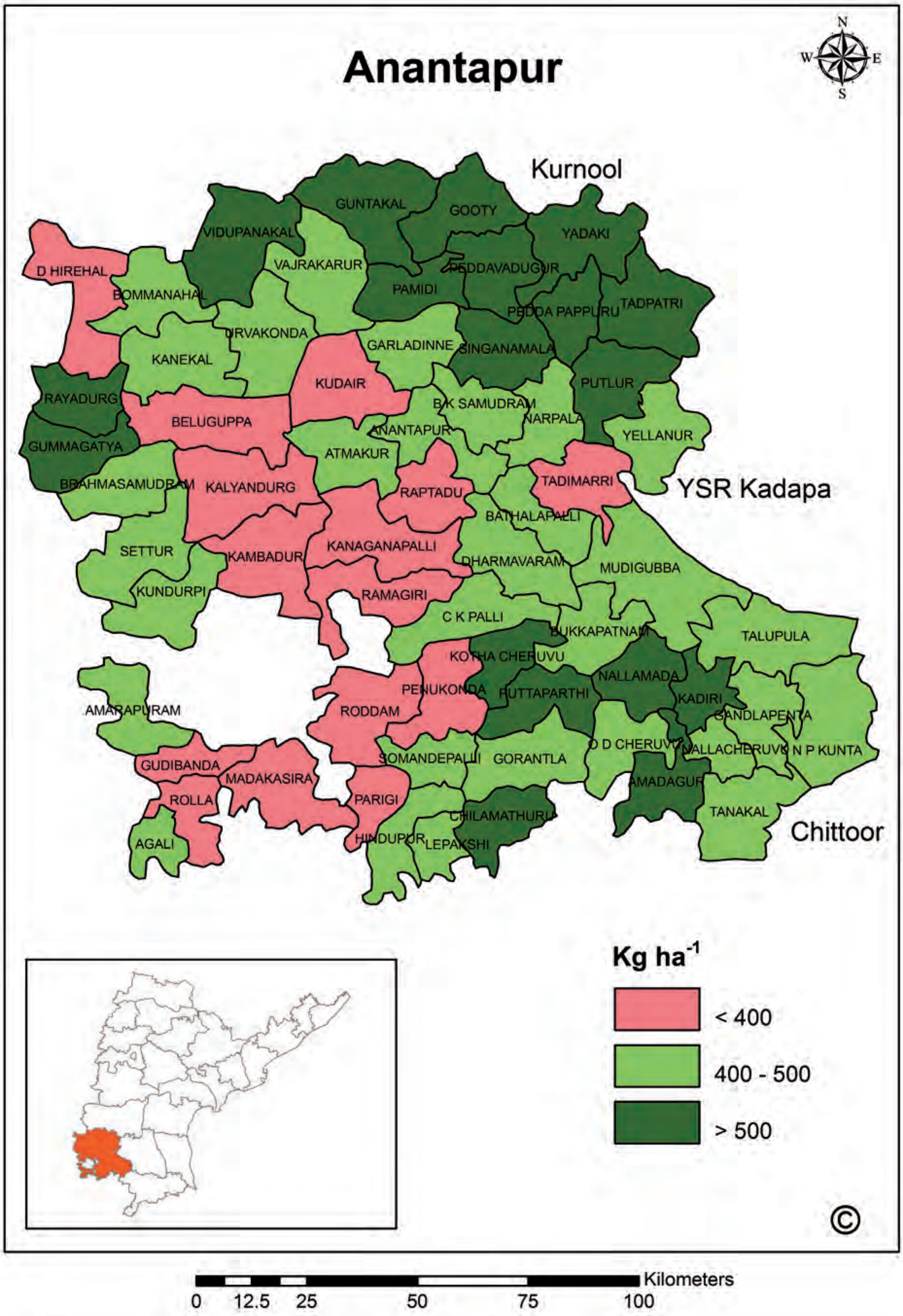
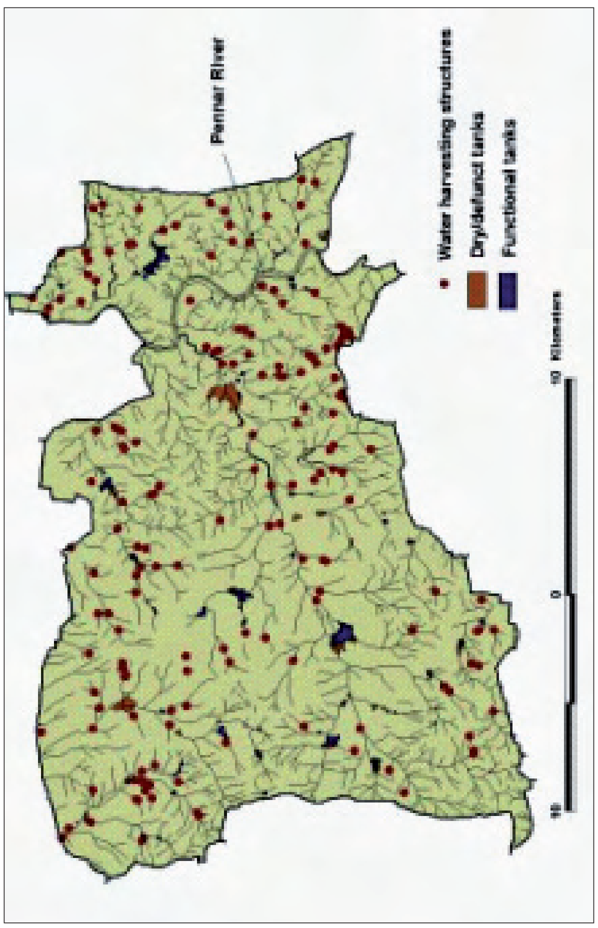


Fig. 174: *Mandal*-wise mean groundnut yields in Anantapur district (1999-2011)



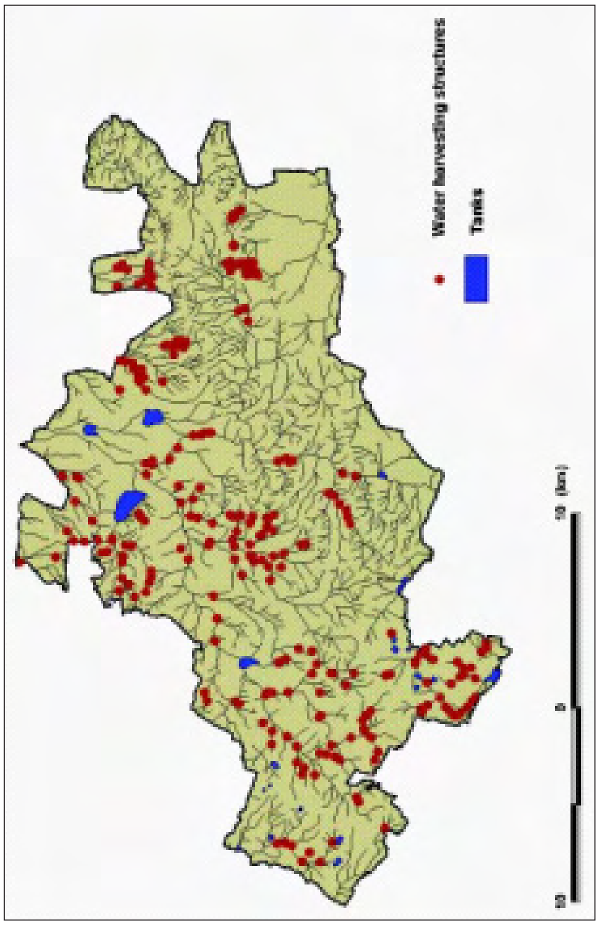


Fig. 175: Water harvesting structures of Kalyandurg (left) and Dhone (right) mandals

Annexure-I

Details for *mandals* and length of data used for rainfall analysis (1971-2011)

District	Total No. of *Mandals*	No. of *Mandals*				
		Less than 10 and 10	11-19	20-29	30-39	40 and above 40
Adilabad	52	-	25	16	3	8
Anantapur	63	-	-	35	14	14
Chitoor	66	-	1	42	13	10
YSR Kadapa	51	-	11	28	3	9
East Godavari	60	1	14	29	7	9
Guntur	57	-	17	24	11	5
Karimnagar	57	1	16	29	4	7
Khammam	46	-	8	24	6	8
Krishna	50	-	9	28	3	10
Kurnool	54	-	4	26	10	14
Mahabubnagar	64	-	3	49	12	-
Medak	46	1	-	37	-	8
Nalgonda	59	1	8	42	2	6
SPSR Nellore	46	-	7	30	-	9
Nizamabad	36	-	2	26	5	3
Prakasam	56	3	11	32	4	6
Ranga Reddy	37	-	3	25	3	6
Srikakulam	38	-	4	27	-	7
Visakhapatnam	43	1	8	24	3	7
Vizianagaram	34	-	5	20	3	6
Warangal	51	1	9	35	1	5
West Godavari	46	-	3	27	8	8
Total	**1112**	**9**	**168**	**655**	**115**	**165**

Annexure-II

Details of stations with datum length and weather parameters considered for analysis

S. No	Station	District	Max T	Min T	RH1	RH2	WS	SSH	EVP
1	Mudhol	Adilabad	2002-2010	2002-2010	NA	NA	NA	NA	NA
2	Adilabad	Adilabad	2009-2011	2009-2011	2009-2011	2009-2011	NA	NA	NA
3	Anantapur	Anantapur	1966-2010	1966-2010	1966-2010	1967-2010	1980-2010	1980-2010	1971-2010 (1974-NA)
4	Kadiri	Anantapur	2000-2007	2000-2007	NA	NA	NA	NA	NA
5	Arogyawaram	Chittor	1969-2005, 2008-2009	1969-2005, 2008-2009	NA	NA	NA	NA	NA
6	Tirupati	Chittor	1990-2005, 2007-2010	1990-2005, 2007-2010	1990-2005, 2007-2010	1990-2005, 2007-2010	2000-2010	1990-2005, 2007-2010	2000-2010
7	Nalgonda	Nalgonda	1998-2000, 2002, 2004-2005, 2007-2009, 2011	1998-2000, 2002, 2004-2005, 2007-2009, 2011	2011	NA	NA	NA	NA
8	Utukur	YSR Kadapa	2000-2010	2000-2010	NA	NA	NA	NA	NA
9	Jagtiyal	Karimnagar	1986-2010	1986-2010	NA	NA	NA	NA	NA
10	Madhira	Khammam	1998-2011	1998-2011	NA	NA	NA		NA
11	Machilipatnam	Krishna	1969-2005, 2007-2011	1969-2005, 2007-2011	NA	NA	NA	NA	NA
12	Kurnool	Kurnool	1969-2005, 2007-2011	1969-2005, 2007-2011	NA	NA	NA	NA	NA
13	Mahabubnagar	Mahabubnagar	1969-1994, 1996-2005, 2007-2011	1969-1994, 1996-2005, 2007-2011	NA	NA	NA	NA	NA
14	Patancheru	Medak	1975-2011	1975-2011	1975-2011	1975-2011	1975-2011	1975-2011	

S. No	Station	District	Max T	Min T	RH1	RH2	WS	SSH	EVP
15	Amadalavalsa	Srikakulam	1998-2007	1998-2007	NA	NA	NA	NA	NA
16	Anakapalle	Vishakapatnam	1981-2011	1981-2011	1981-2011	1981-2011	1981-2011	1981-2011	1981-2011
17	Ananrajupet	YSR Kadapa	1979-2009	1979-2009	1979-2009	1979-2009	NA	NA	NA
18	Aswaraopet	Khammam	2000-2006	2000-2006	2000-2006	2000-2006	2000-2006	2000-2006	2000-2006
19	Bapatla	Guntur	1998-2005, 2007-2008	1998-2005, 2007-2008	NA	NA	NA	NA	NA
20	Bhadrachalam	Khammam	2001-2005, 2007-2009	2001-2005, 2007-2009	NA	NA	NA	NA	NA
21	Darsi	Prakasam	1996-2007	2007	2000-2007	2000-2007	2000-2007		2000-2007
22	Gannawaram	Krishna	1969-2001	1969-2001	NA	NA	NA	NA	NA
23	Garikapadu	Guntur	1990-1993, 2001-2005	1990-1993, 2001-2005	NA	NA	NA	NA	NA
24	Hakimpet	Ranga Reddy	1998-2005, 2007-2011	1998-2005, 2007-2011	1998-2005, 2007-2011	NA	NA	NA	NA
25	Hanamakonda	Warangal	1969-2005, 2007-2009, 2011	1969-2005, 2007-2009, 2011	NA	NA	NA	NA	NA
26	Hayathnagar	Ranga Reddy	1976-1981, 1983, 1985-2011	1976-1981, 1983, 1985-2011	1976-1981, 1983, 1985-2011	1976-1981, 1983, 1985-2011	1976-1981, 1983, 1985-2011	1976-1981, 1983, 1985-2011	1976-1981, 1983, 1985-2011
27	Hyderabad	Hyderabad	1998-2005, 2007-2011	1998-2005, 2007-2011	NA	NA	NA	NA	NA
28	Jagtiyal	Karimnagar	1980-2010	1980-2010	1980-2010	1980-2010	1980-2010	1980-2010	1980-2010
29	Kakinada	East Godavari	1998-2005, 2007-2011	1998-2005, 2007-2011	NA	NA	NA	NA	NA
30	Kalingapatnam	Srikakulam	1998-2005, 2007-2009	1998-2005, 2007-2009	NA	NA	NA	NA	NA

S. No	Station	District	Max T	Min T	RH1	RH2	WS	SSH	EVP
31	Kandhukur	Prakasam	2001-2010	2001-2010	2001-2010	2001-2010	NA	2001, 2004-2010	2001-2010
32	Kavali	SPSR Nellore	1998-2005	1998-2005	NA	NA	NA	NA	NA
33	Khammam	Khammam	1998-2005, 2007-2009	1998-2005, 2007-2009	NA	NA	NA	NA	NA
34	Kurnool	Kurnool	1969-2005, 2007-2009	1969-2005, 2007-2009	NA	NA	NA	NA	NA
35	Lam	Guntur	1988-2010	1988-2010	1988-2010	1988-2010	1988-2010	1988-2010	1988-2010
36	Machilipatnam	Krishna	1969-2005, 2007-2011	1969-2005, 2007-2011	NA	NA	NA	NA	NA
37	Madhira	Khammam	1998-2010	1998-2010	NA	NA	NA	NA	NA
38	Mahabubnagar	Mahabubnagar	1969-2005, 2007-2011	1969-2005, 2007-2011	NA	NA	NA	NA	NA
39	Maruteru	West Godavari	1998-2010	1998-2010	1998-2010	1998-2010	1998-2010	1998-2010	1998-2010
40	Medak	Medak	1980-2005, 2007-2009, 2011	1980-2005, 2007-2009, 2011	NA	NA	NA	NA	NA
41	Nagarjunasagar	Nalgonda	1998-2010	1998-2010	NA	NA	NA	NA	1998-2010
42	Naira	Srikakulam	1999-2010	2001-2010	1999-2010	1999-2010	NA	NA	NA
43	Nalgonda	Nalgonda	1998-2005, 2007-2009, 2011	1998-2005, 2007-2009, 2011	NA	NA	NA	NA	NA
44	Nandigama	Krishna	1998-2005, 2007-2009, 2011	1998-2005, 2007-2009, 2011	NA	NA	NA	NA	NA
45	Narkhoda	Ranga Reddy	2001-2010	2001-2010	2001-2010	2001-2010	NA	2001-2010	2001-2010
46	Narsapur	Medak	1998-2011	1998-2011	NA	NA	NA	NA	NA
47	SPSR Nellore	SPSR Nellore	1984-2010	1984-2010	NA	NA	NA	NA	NA

S. No	Station	District	Max T	Min T	RH1	RH2	WS	SSH	EVP
48	Nizamabad	Nizamabad	1998-2005, 2007-2010	1998-2005, 2007-2010	NA	NA	NA	NA	NA
49	Ongole	Prakasam	1969-2005, 2007-2009	1969-2005, 2007-2009	NA	NA	NA	NA	NA
50	Palem	Mahabubnagar	1994-2010	1994-2010	1994-2010	1995-2010	1996-2010	1996-2010	1996-2010
51	Patancheru	Medak	1974-2011	1974-2011	1974-2011	1974-2011	1974-2011	1975-2011	1974-2011
52	Peddapuram	East Godavari	2004-2010	2004-2010	2004-2010	2004-2010	NA	NA	NA
53	Ragolu	Srikakulam	2003-2005	2003-2005	2003-2005	2003-2005	2003-2004	2003-2004	NA
54	Rajendranagar	Ranga Reddy	1966-2010	1966-2010	1966-2010	1966-2010	1966-2010	1966-2010	1966-2010
55	Rajhamundry	East Godavari	1960-1978, 1980-2010	1960-1978, 1980-2010	1960-1978, 1980-2010	1960-1978, 1980-2010	1960-1978, 1980-1987, 1991-2010	1960-1978, 1980-2005, 2008-2010	1960-1978, 1980-1993, 1998-1999, 2003-2010
56	Rentachintala	Guntur	1969-2001	1969-2001	NA	NA	NA	NA	NA
57	Rurdrur	Nizamabad	1963-2003	1963-2003	1963-1992, 1994-2000, 2002-2003	1963-1992, 1994-2000, 2002-2003	1963-1979	NA	1984-1991
58	Tuni	East Godavari	1998-2011	1998-2011	NA	NA	NA	NA	NA
59	Vijayawada AP	Krishna	1998-2009	1998-2009	NA	NA	NA	NA	NA
60	Visakhapatnam	Visakhapatnam	1998-2009	1998-2009	NA	NA	NA	NA	NA
61	Vizianagaram	Vizianagaram	1999-2005	1999-2005	NA	NA	IMD normal	NA	NA
62	Warangal	Warangal	1992-2010	1992-2010	1999-2002, 2004-2006, 2008-2010	1999-2002, 2004-2006, 2008-2010	NA	NA	2004-2006, 2008-2009

Annexure - III

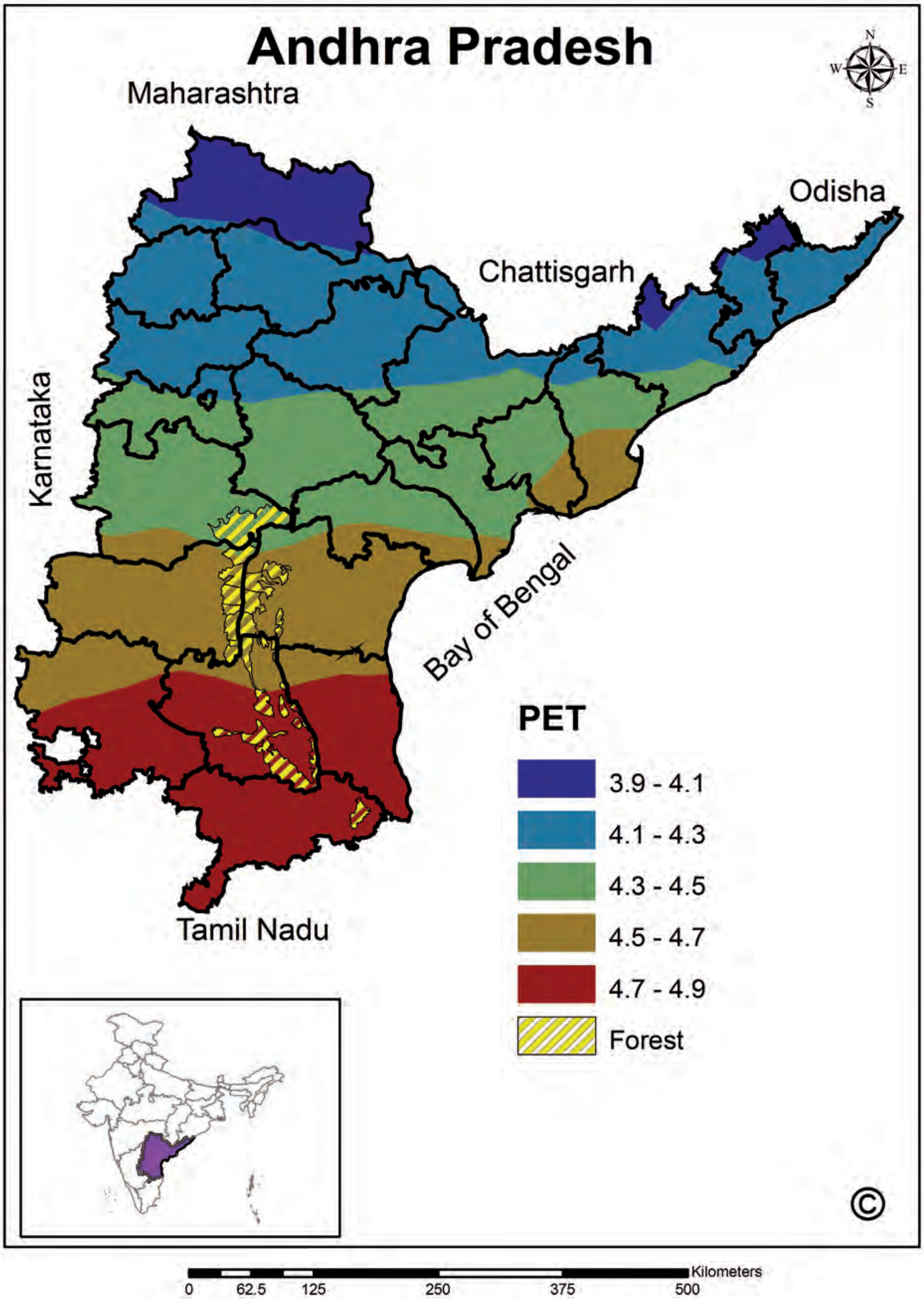


Fig. A1: Potential evapotranspiration (mm/day) for the month of January over Andhra Pradesh

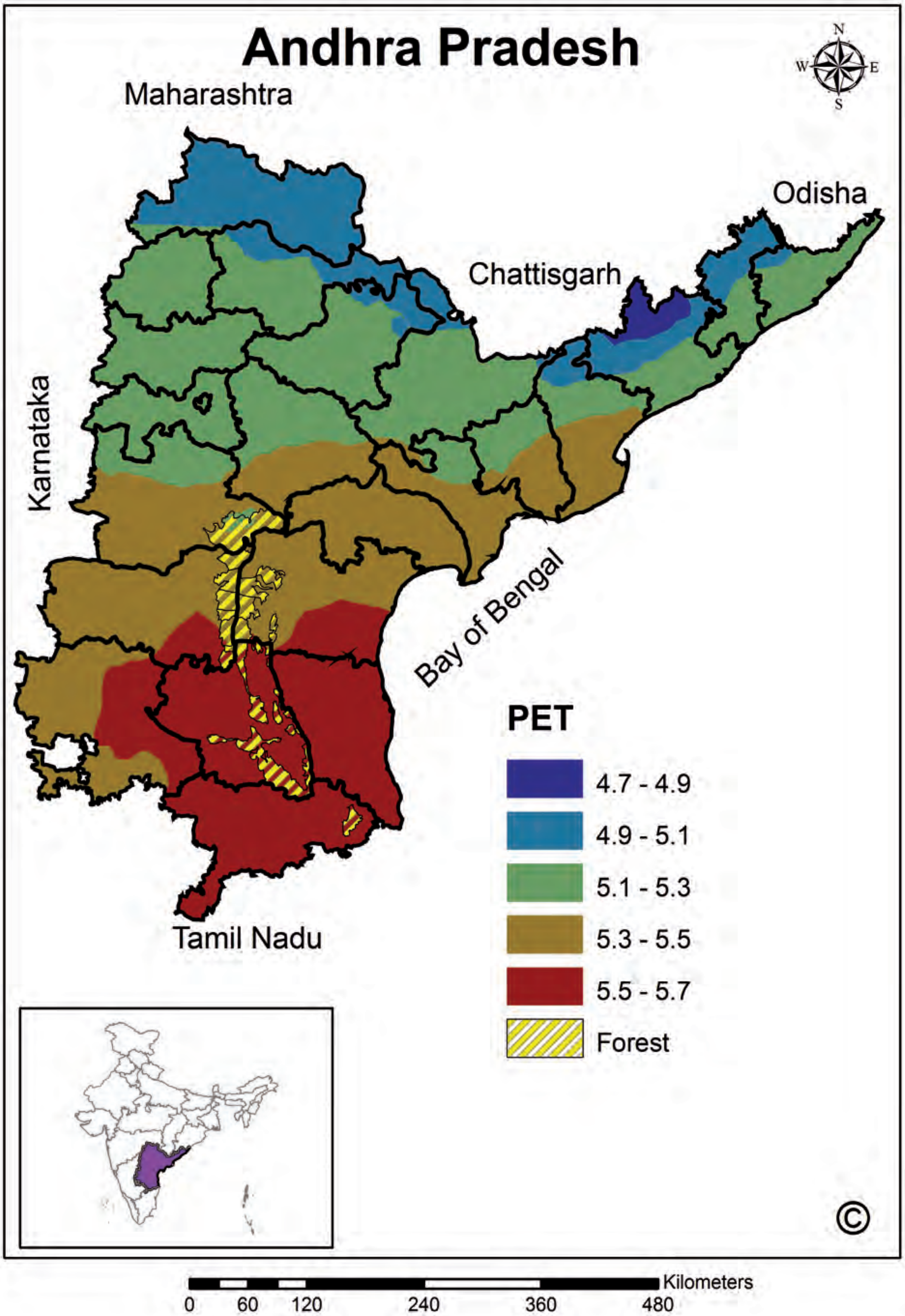


Fig. A2: Potential evapotranspiration (mm/day) for the month of February over Andhra Pradesh

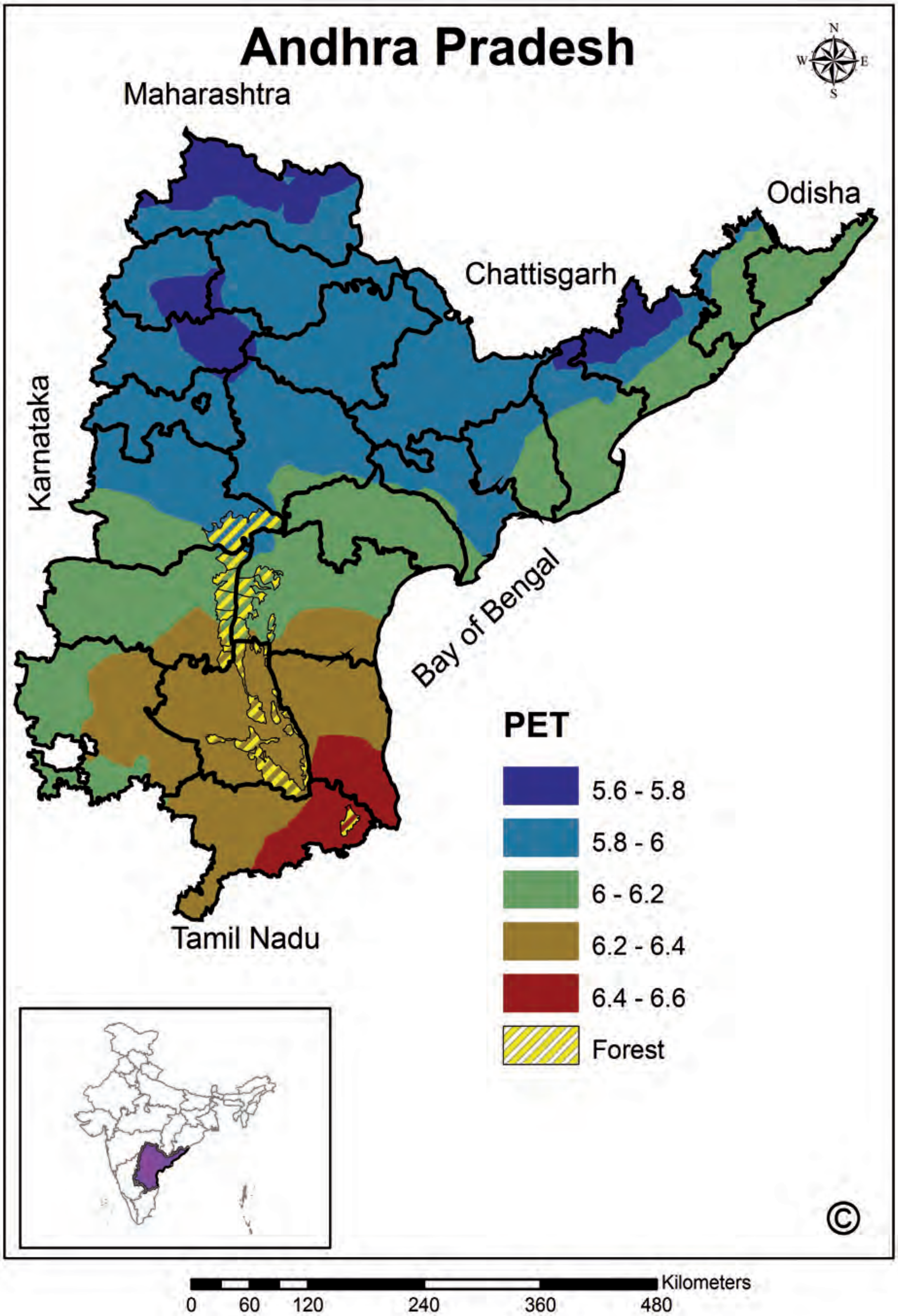


Fig. A3: Potential evapotranspiration (mm/day) for the month of March over Andhra Pradesh

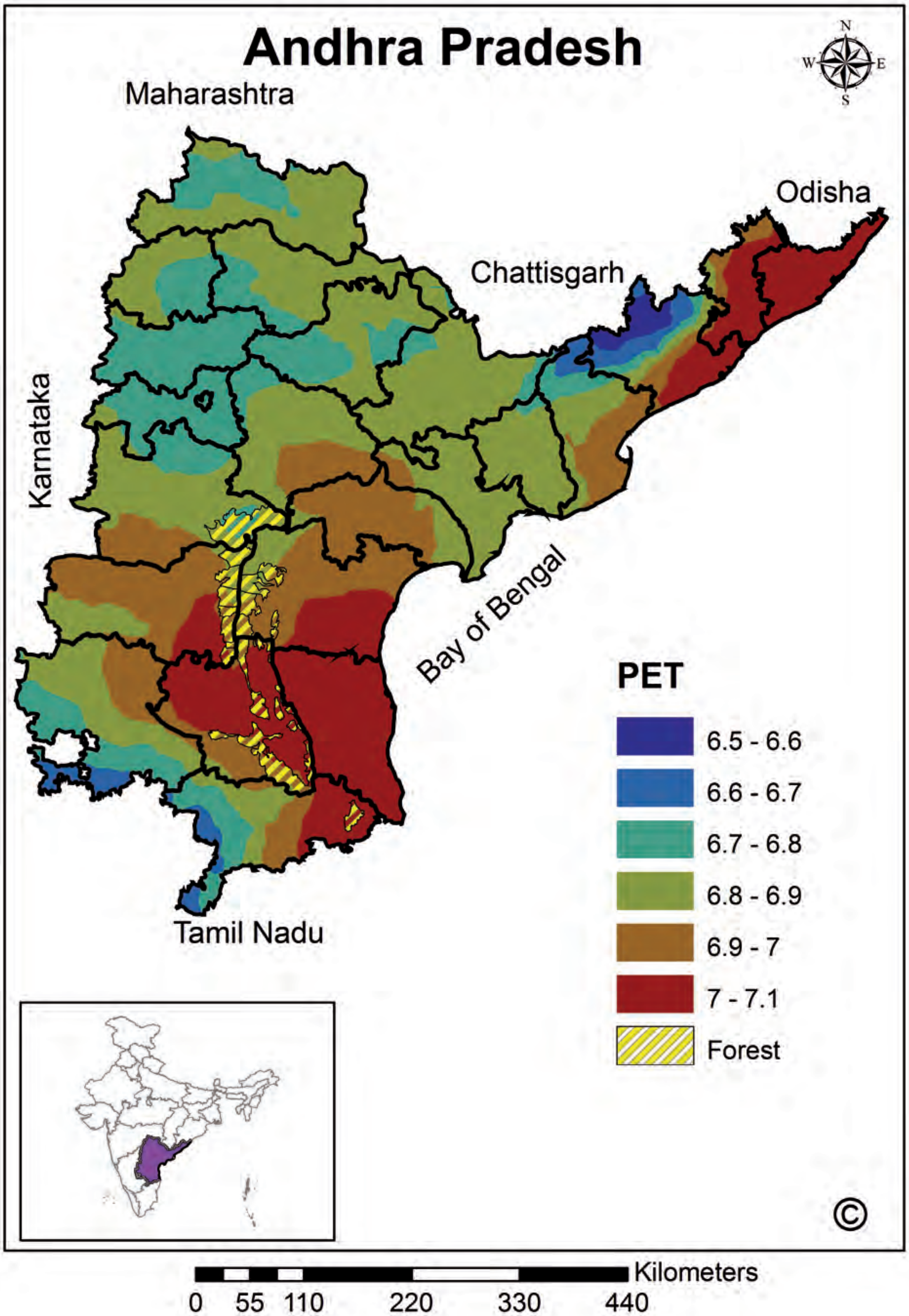


Fig. A4: Potential evapotranspiration (mm/day) for the month of April over Andhra Pradesh

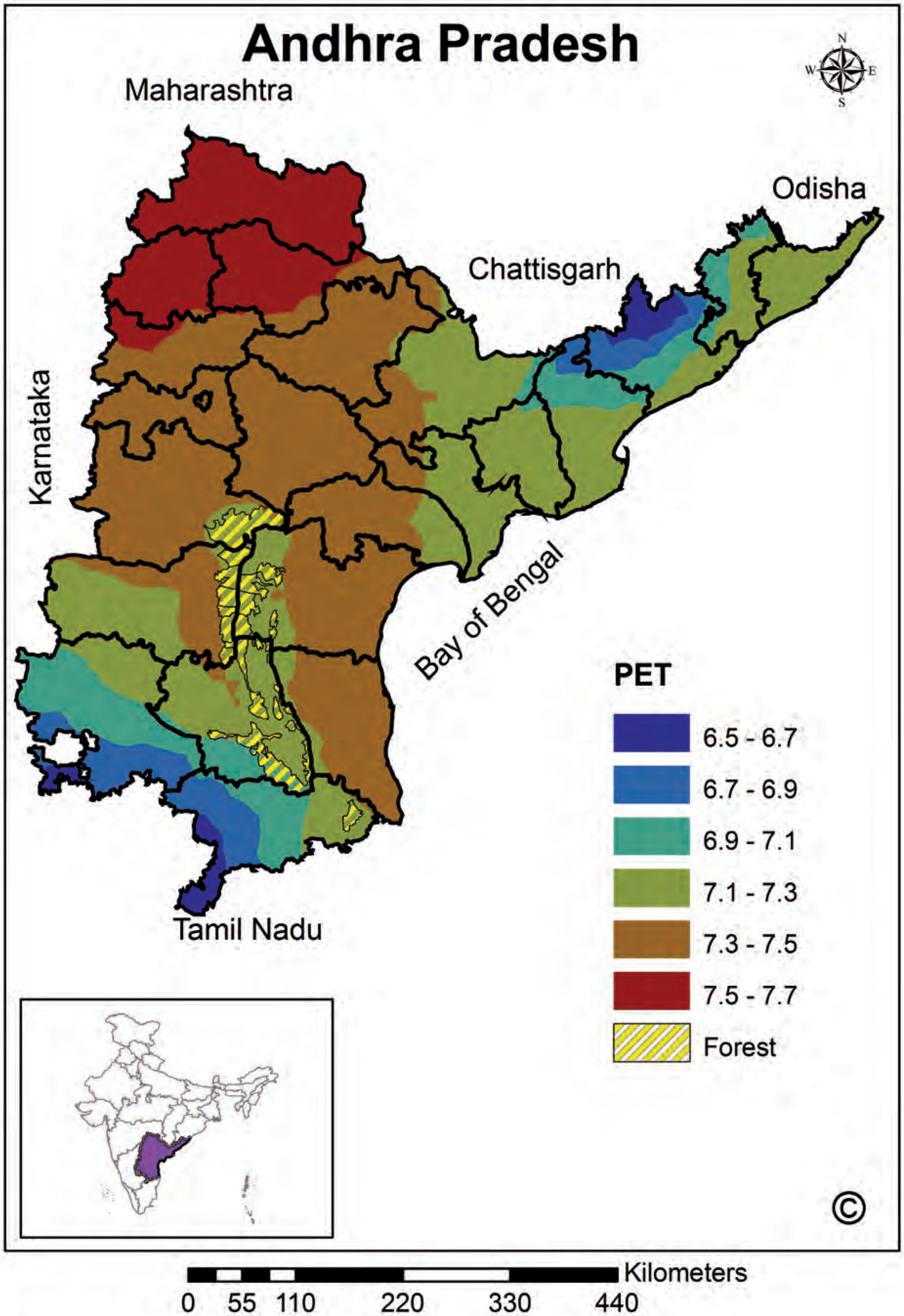


Fig. A5: Potential evapotranspiration (mm/day) for the month of May over Andhra Pradesh

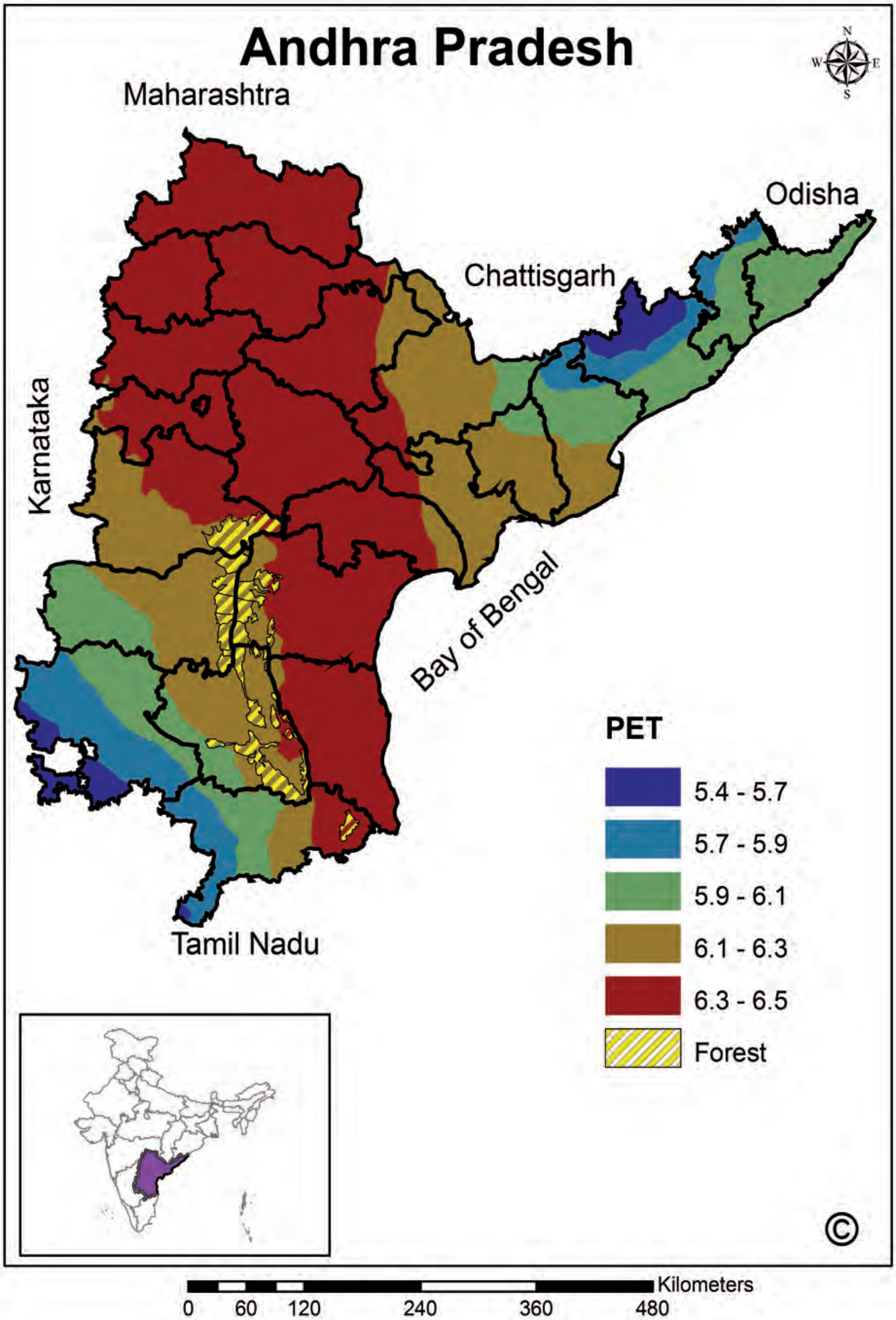


Fig. A6: Potential evapotranspiration (mm/day) for the month of June over Andhra Pradesh

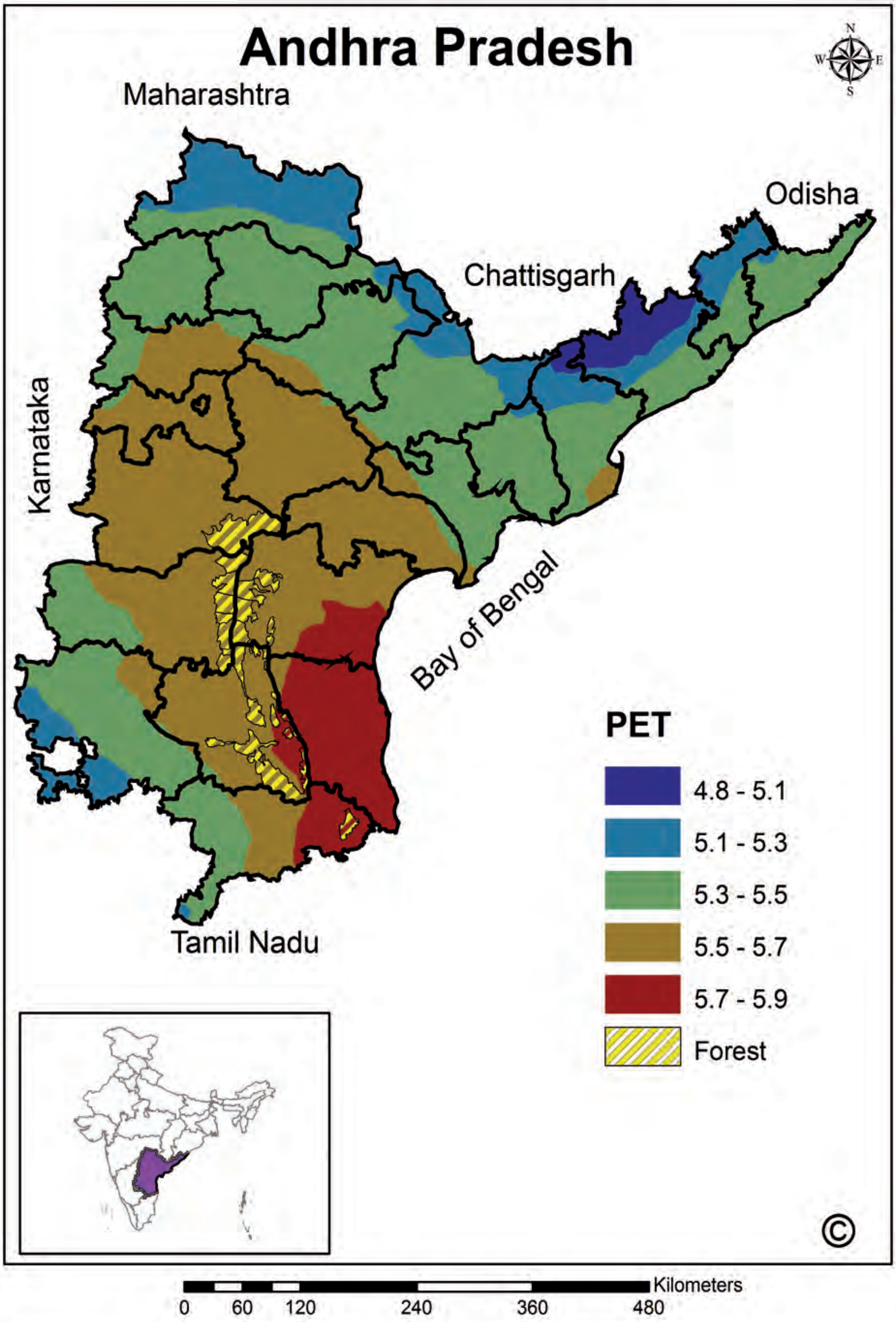


Fig. A7: Potential evapotranspiration (mm/day) for the month of July over Andhra Pradesh

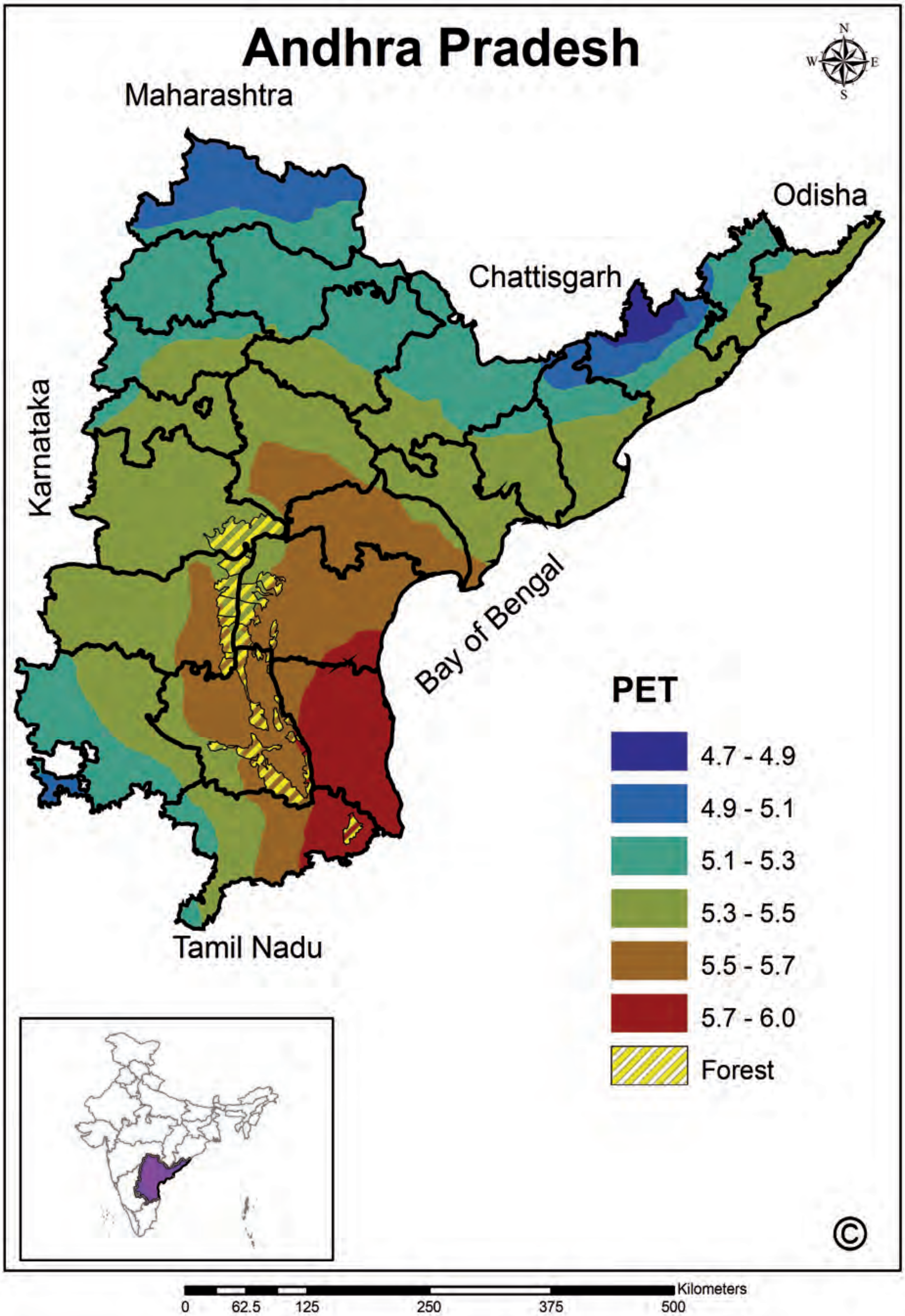


Fig. A8: Potential evapotranspiration (mm/day) for the month of August over Andhra Pradesh

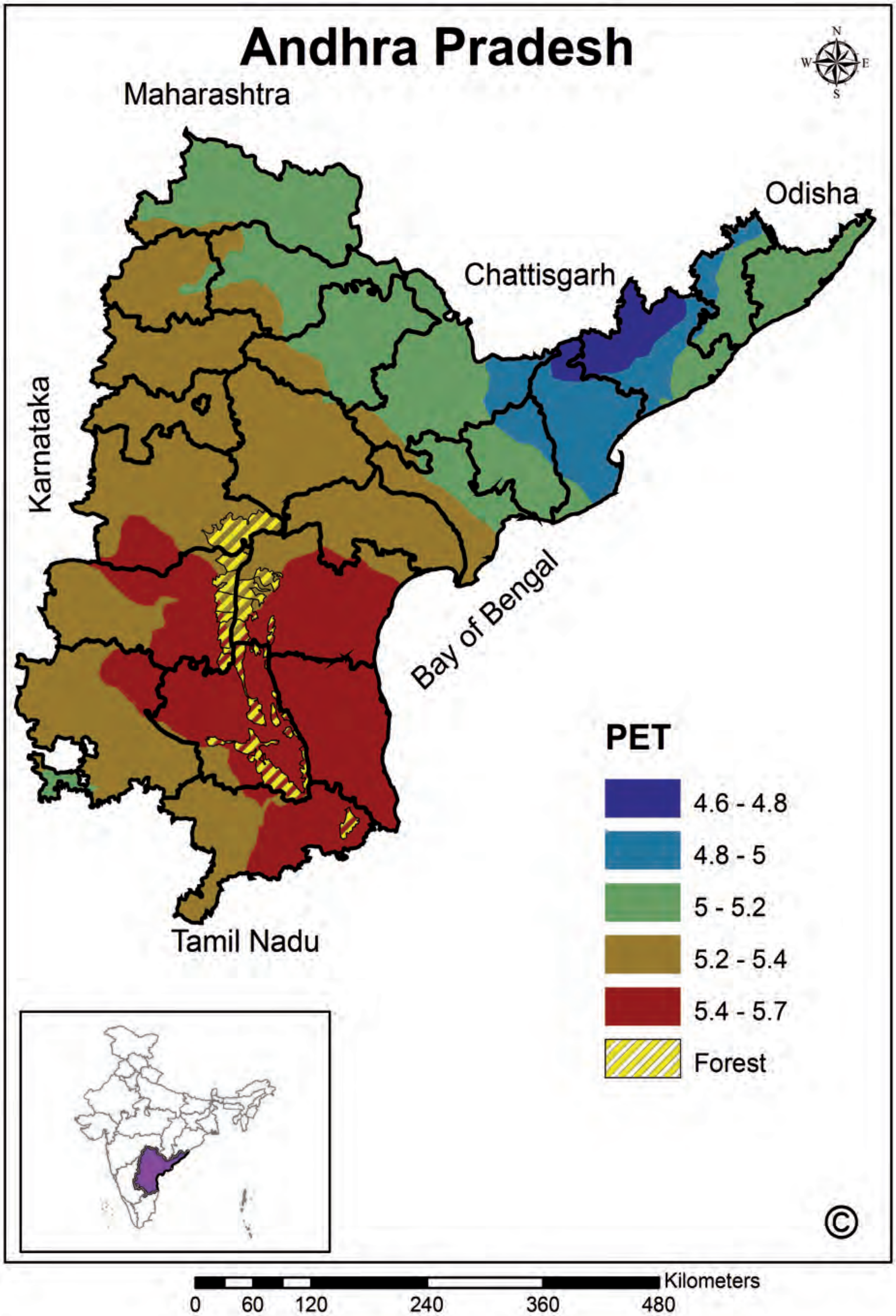


Fig. A9: Potential evapotranspiration (mm/day) for the month of September over Andhra Pradesh

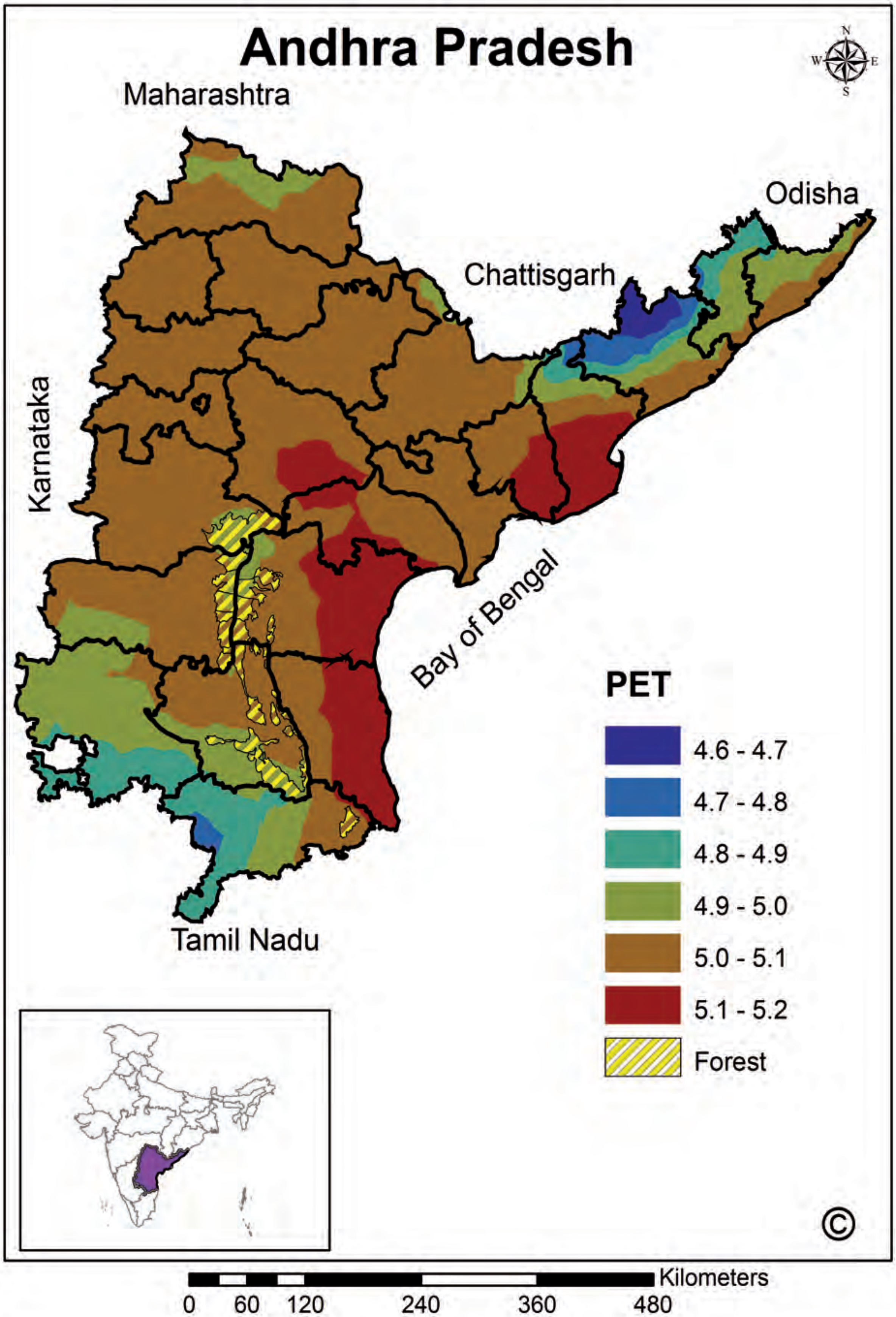


Fig. A10: Potential evapotranspiration (mm/day) for the month of October over Andhra Pradesh

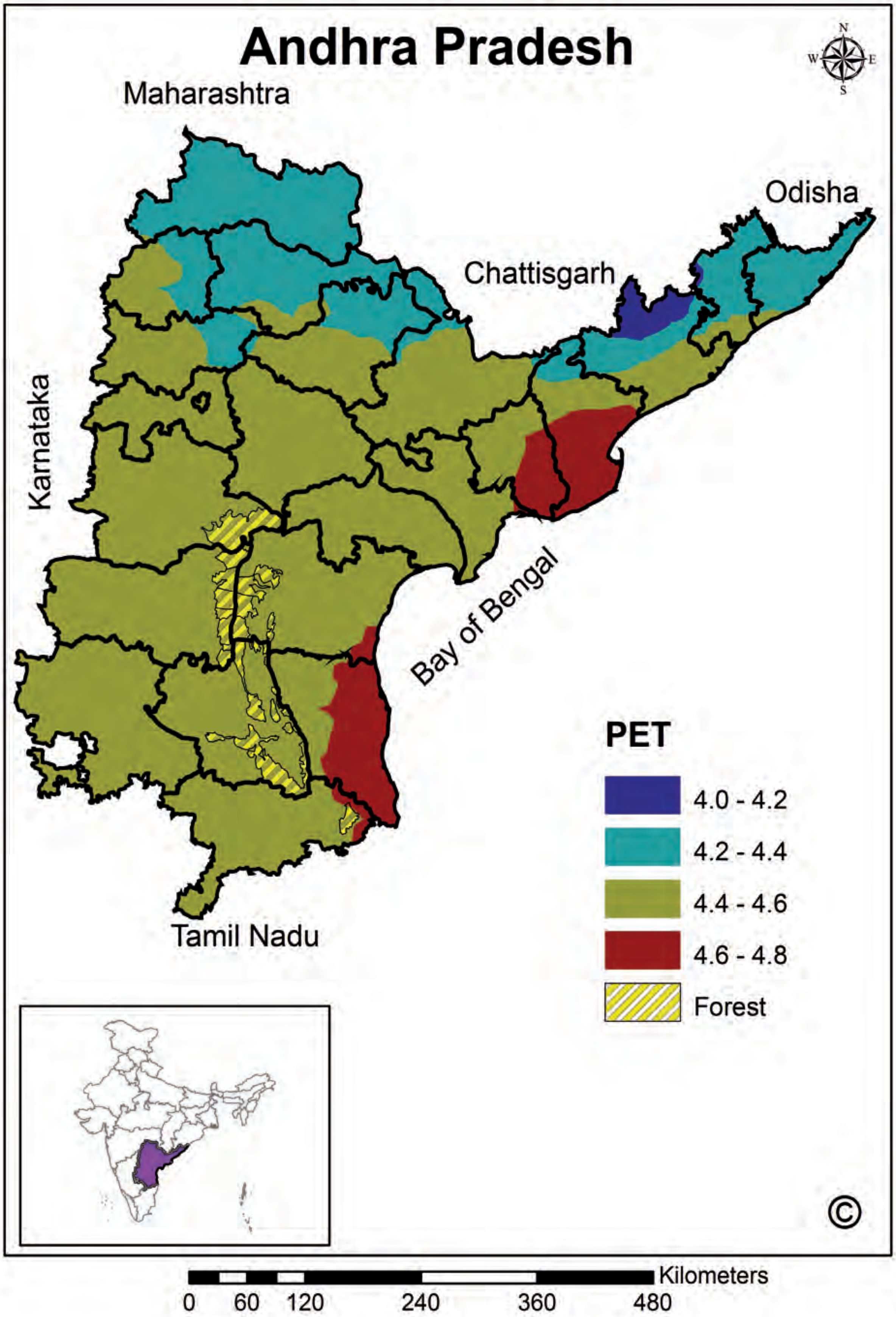


Fig. A11: Potential evapotranspiration (mm/day) for the month of November over Andhra Pradesh

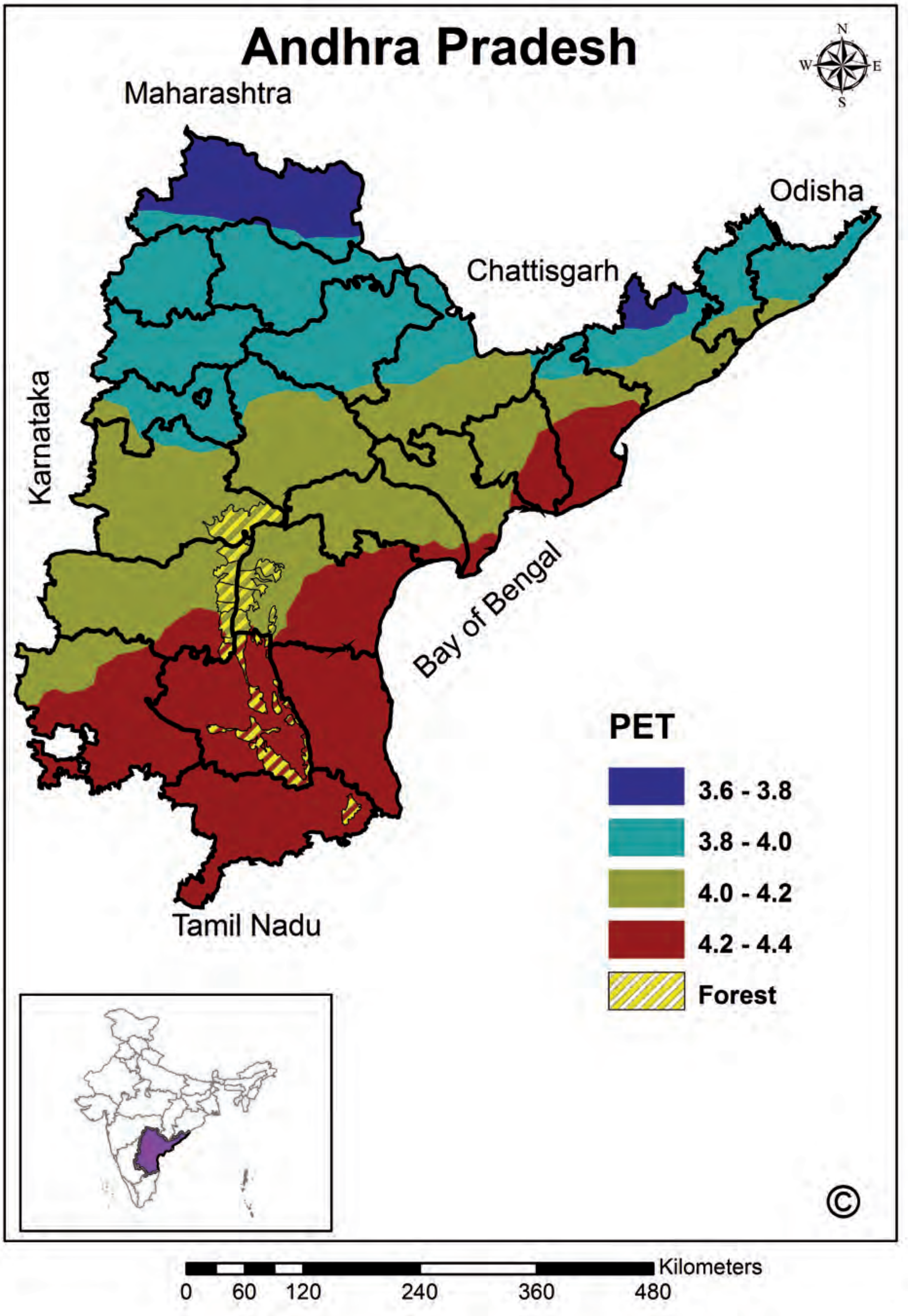


Fig. A12: Potential evapotranspiration (mm/day) for the month of December over Andhra Pradesh