Agroclimatic Atlas of Maharashtra

K.K. Dakhore, Anil Karunakar, J.D. Jadhav, D.N. Jagtap,
P.B. Pawar and P. Vijaya Kumar

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Fax : 91 - 02452 - 220121
Web : *www.vnmkv.nic.in*
E-mail : directorresmkv@rediffmail.com

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AGROCLIMATIC ATLAS OF MAHARASHTRA

K.K. Dakhore
Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani

Anil Karunakar
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola

J.D. Jadhav
Mahatma Phule Krishi Vidyapeeth, Rahuri

D.N. Jagtap
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

P.B. Pawar
Mahatma Phule Krishi Vidyapeeth, Rahuri

P. Vijaya Kumar
AICRP on Agrometeorology
Central Research Institute for Dryland Agriculture, Hyderabad

Under the Guidance of

Dr. B. Venkateswarlu
Vice-Chancellor
VNMKV, Parbhani

Dr. Tapas Bhattacharyya
Vice-Chancellor
Dr.BSKKV, Dapoli

Dr. K.P. Viswanatha
Vice-Chancellor
MPKV, Rahuri

Dr. V.M. Bhale
Vice-Chancellor
Dr.PDKV, Akola

Dr. D.P. Waskar
Director of Research
VNMKV, Parbhani

Dr. S.R. Gadakh
Director of Research
MPKV, Rahuri

Dr. V.K. Kharche
Director of Research
Dr.PDKV, Akola

Dr. P.M. Haldankar
Director of Research
Dr.BSKKV, Dapoli

Devendra Fadnavis
Chief Minister
Maharashtra

सत्यमेव जयते

MESSAGE

Weather and climate play an important role in agricultural production especially in States like Maharashtra where 83 per cent area depends on monsoon rains. Climate change in recent period is adding further uncertainty to the *kharif* crop production in the State. Back to back droughts, heavy rainfall events, heat wave, frost and hail storms are causing enormous losses to farmers across the State year after year. When farmers plant high water requiring crops in drought prone regions, they often lose the entire crops during severe droughts and water shortage. Therefore it is important to have scientific land capability and climate based cropping pattern which not only optimizes production but also reduces risks to the farmers.

In this context, the first step is to analyse and document the agro climatic features of different parts of the State which will then enable for scientific crop planning and risk mitigation. I am happy to note that all the four agricultural universities in Maharashtra have come together and jointly prepared the first ever "Agro Climatic Atlas of Maharashtra". The Atlas provides district wise detailed data on historical rainfall, potential evapotranspiration, minimum and maximum temperatures, rainfall probabilities, relative humidity, length of growing period, soil moisture and water balance etc. which are critical parameters for crop planning and tackling contingency situations. The district wise current cropping pattern and efficient cropping zones based on climate are also suggested. This atlas will be highly useful for all researchers and planners interested in scientific agricultural planning in the state. I am sure that the Atlas will be widely used for implementation of the proposed Nanaji Deshmukh Krishi Sanjivani Prakalp on climate resilient agriculture in Marathwada and Vidarbha regions.

I compliment all the Vice-Chancellors for taking up such an initiative and bringing out an important publication.

(Devendra Fadnavis)

Pandurang Fundkar
Minister of Agriculture & Horticulture
Maharashtra State

सत्यमेव जयते

FOREWORD

Climate change is a major concern for agriculture in India, more so in Maharashtra where agriculture is mainly rainfed. Climate change and variability are having a significant impact on agriculture, water resources, live stock production and fodder availability. In order to cope with climate change, the state need to develop and appropriate cropping pattern and follow scientific crop management practices which match the rainfall, soil type and water availability in different regions of the state.

For any scientific agriculture planning, it is important to fully characterize the climate of different regions and districts and follow appropriate cropping pattern matching with the land capability and water availability. I understand that all the four agriculture universities in Maharashtra have joined together and prepared for the first time the "Agro Climatic Atlas of Maharashtra", which is being released on the occasion of the 45th Joint Agresco being held at Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. This Atlas has all useful information on climate at district level and presented in an excellent manner in maps and diagrams. I am sure the Atlas will be quite useful to Department of Agriculture.

I congratulate the Vice Chancellors of SAUs for this valuable publication.

(Pandurang Fundkar)

Acknowledgments

Agricultural production in the state of Maharashtra 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 SAU's. We tried to extract information and presented in a simple and practically usable form. We profusely thank Dr. B. Venkateswarlu, Hon ble Vice-Chancellor, VNMKV, Parbhani for his keen interest, support and guidance at all stages of the study. We are thankful to Dr. Tapas Bhattacharyya, Hon ble Vice-Chancellor, Dr.BSKKV, Dapoli, Dr. K.P. Viswanatha, Hon ble Vice-Chancellor, MPKV, Rahuri and Dr. V.M. Bhale , Hon ble Vice-Chancellor, Dr.PDKV, Akola for their support.

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AUTHORS

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Executive Summary

Crop production mainly governed by climate. Increased climatic variability and climate change are causing significant negative impacts on agricultural production and farmers livelihoods. For effective planning of the agricultural production systems in a region, a detailed analysis of climatic/ information is a pre-requisite. For farm level decisions and risk management, weather information at micro level is needed. Climatic information at micro (*taluka*) level for the state of Maharashtra has not been available hitherto. This Agroclimatic Atlas for the state of Maharashtra is brought out covering all aspects of agrometeorology. The aim of this Atlas is to demonstrate how agroclimatological analysis could form a basis for proper crop planning in the state.

Agricultural scenario of Maharashtra

Paddy, sorghum and pearl millet are the principal cereal crops of Maharashtra. Area under paddy is about 15 lakh ha and there is a marginal increase in its area over the years. Sorghum is the second largest cereal crop due to its value as grain and fodder. It is grown both in *kharif* and *rabi* season. Pearl millet is another important cereal crop grown mostly in semi-arid region of Maharashtra. The area under *kharif* sorghum has fallen from 31.1 lakh ha to 6.2 lakh ha in last 55 years. Productivity level of *kharif* sorghum has increased from 305 kg ha in 1972 to 1425 kg ha in 2011. However, in the case of *rabi* sorghum, the area has decreased from 37.8 lakh ha in the 1971 to 15.1 lakh ha in 2013. Area under pearl millet also decreased sharply during 1960-2015.

The major pulse crops of the state are red gram, black gram and green gram. Area under red gram has picked up in recent years. Red gram area has risen from 5.30 lakh ha during 1960-61 to 13.01 lakh ha in 2010. This rise is partly due to introduction of pulses improvement program and partly due to market forces. The inter-annual variability in area under this crop is largely weather driven. Area, production and productivity of black gram varied over the years. Area and production under green gram has showed a marginal ascent in recent years but productivity levels have been sustained / enhanced due to use of improved package of practices.

Groundnut, soybean and safflower are the major oilseeds crops of Maharashtra. Soybean area occupies the largest area. Area under soybean crop increased from 0.7 lakh ha in 1987 to 36.4 lakh ha in 2014. Its production and productivity have shown a sharp increase over the years. Major shift that occurred in the past decades in favour of soybean crop was due to its early duration, suitability to double cropping, yield advantage, higher price and better market support. The area under soybean has substituted more of *kharif* sorghum and some cotton acreage. Groundnut is grown on 2.41 lakh ha. The production trend of this crop has shown steep decline over the years due to variation in the spread of rainfall. Similarly, area under safflower is also showing a sharp decline with a marginal decrease in production. This may be due to the introduction of improved cultivars and production technology.

Cotton is the principal commercial crop of the state. It is cultivated on more than 41 lakh ha. Though productivity trends show large variability there has been a constant increase in its area and production chiefly due to the introduction of Bt cotton. A steep increase in sugarcane area and production has come through with a concurrent increase in the area over the years. Very small inter-annual variation in the productivity of the crop may be attributed to the fact that large area is irrigated.

a) Rainfall

Annual normal average rainfall of the state is 1204 mm out of which Southwest monsoon (June to September) accounts for 91% and Northeast monsoon (October to December) accounts for 7%. The rest (2% of the rainfall) is received during the winter and summer months. There is a large spatial variability in the distribution of rainfall over different regions. Southwest Monsoon (SWM) provides higher rainfall in the *Konkan* region (2878 mm) followed by the *Vidarbha* (937 mm), *Madhya Maharashtra* (799 mm), and the *Marathwada* (545 mm), whereas Post Monsoon contributes higher rainfall in the *Konkan* area i.e. 134 mm followed by *Madhya Maharashtra* (96 mm), Marathwada (71 mm) and *Vidarbha* (64 mm). There is a large difference in annual rainfall received across the districts with Ratnagiri topping the list (3618 mm), while the lowest rainfall is recorded in Ahmednagar district (547 mm). At the district level, highest variability in the rainfall is observed in Nanded (81 %) followed by Latur (67 %) and Parbhani (65 %) and least in Palghar and Ratnagiri (23 %). Highest variability in post monsoon rainfall is observed in Nanded (136%) followed by Parbhani (132%).

The total annual rainfall is received in 33 to 102 rainy days with a variability of 27%. On an annual, the average number of rainy days in coastal *Konkan* region are 91 which is significantly higher than *Vidarbha* (49 days), *Madhya Maharashtra* (46 days) and *Marathwada* (35 days). Highest numbers of rainy days are observed in Sindhudurg district (102 days).

During SWM the state receives 1090 ± 337 mm. Ratnagiri receives highest annual rainfall (3415 mm). In the *Madhya Maharashtra* region, Kolhapur (1677 mm) and Satara (1204 mm) districts receive relatively higher rainfall. Lowest rainfall is noted in Ahemadnagar district (434 mm) followed by Sangli (445 mm). Lowest variability is seen over Coastal *Konkan* (24%) and *Vidarbha* (30%) and highest in *Marathwada (61%) and it is intermediate over Madhya Maharashtra (36%).* At the district level, highest variability of rainfall is observed in Nanded district (81 %) and lowest in Palghar and Ratnagiri (23 %). SWM rainfall in the state is spread on an average over 45 days. Highest numbers of rainy days are observed in the *Konkan region (83 days) and Vidarbha (43 days)* and lowest over the *Marathwada* region (30 days); and the number of rainy days are intermediate over the *Madhya Maharashtra* (39 days). Ratnagiri and Sindhudurg districts record maximum number rainy days (91 days) while, these were least in Ahemadnagar (26 days).

Rainfall during the Post monsoon for the entire state is 85± 78 mm with a variability of 98%. Coastal *Konkan* receives large amount of rainfall (134 mm), *Madhya Maharashtra* and *Marathwada* receives a fairly good amount of rainfall (96 mm) and (71 mm) respectively while, the lowest Post monsoon rainfall is recorded in the *Vidarbha region (64 mm).* Sindhudurg district receives more rainfall (196 mm) during this season while it is lowest in Nandurbar (46 mm).

Trends in time series

Around 78 percent of the *talukas* in the state showed no significant trend. However, majority of the *talukas in Kolhapur district* showed declining trend in annual rainfall followed by Satara, Solapur, Aurangabad, Nanded and Yavatmal districts. On the other hand, increasing trend in annual rainfall is observed in many *talukas of Nanded, Latur, Parbhani and also a few talukas of Hingoli, Beed and Jalna districts.*

In 3 out of 17 *talukas* of Kolhapur district, a declining trend was observed in SWM rainfall. At the same time, increasing tendency in SWM is observed in few *talukas* of Nanded and Aurangabad followed by Beed, Latur, Ahemadnagar, Jalgaon and Parbhani districts. The trend of number of rainy days showed similar pattern to rainfall. However, a declining trend is seen in few *talukas*.

Generally, no significant trend in the number of rain events was observed in most parts of the state under both categories (75-100 mm and >100 mm/day). However, significant increasing trend in 75-100 mm category is noted in many *talukas* of *Ratnagiri, Pune, Raigadh, Nanded, Palghar, Parbhani, Osmanabad, and Beed districts.* A declining trend is observed in Solapur, Gadchiroli, Jalgaon, Parbhani, Kolhapur, Nagpur, Amravati, Bhandara, Yavatmal, Buldhana and Satara districts in 75-100 mm category.

Rainfall during SWM significant increasing or decreasing trends in 75-100 mm/day-category is observed in 6 and 8 *talukas*, respectively. Maximum number of *talukas* showing significant increasing trend are seen in Thane and Buldhana. Declining trend is observed in Parbhani , Yavatmal, Amravati, Gadchiroli, Latur, Nashik, Kolhapur, Bhandara and Nanded districts. A few *talukas* of Thane, Nanded and Beed districts showed significant increasing trend whereas declining trend was noted in some *talukas* of Buldhana and Yavatmal districts in the >100 mm rainfall category.

No significant trend is observed in maximum one-day rainfall in majority of *districts* (4 out of 32 *districts*). High daily rainfall episodes showed an increasing trend mainly over *Madhya Maharashtra* region while a declining trend is noted over the *Marathwada, Vidharbha and Madhya Maharashtra.*

A significant increasing trend in maximum 5-day cumulative rainfall is noted in two *talukas viz.,* Nagpur and Nashik *districts* and a declining trend in Wardha, Ratnagiri and Solapur *districts*. Out of 32 *districts* analyzed, only three showed increasing tendency in mean daily rainfall intensity. On the other hand, only seven *districts viz.,* Akola, Aurangabad, Beed, Hingoli, Jalana, Nanded and Solapur *districts* showed a declining trend.

No significant trend is noted in 91 per cent (29 out of 32) *districts* analyzed with respect to length of dry spell. An increasing trend is evident in two *districts,* out of which one is located in Yavatmal and one in Jalna. A declining trend is observed in *Chandrapur* district. There is no significant trend in length of continuous wet spells in 8 out of 32 *districts*. The length of wet spells showed an increasing trend in 2 *districts which* are located in the Marathwada and two in *Madhaya Maharashtra* region. A declining trend is observed only in two *districts viz.,* Gondia and Nashik

Except in Latur, Nanded, Akola, Amravati, Bhandara, Buldhana, Chandrapur, Wardha, Yavtamal and Jalgaon, the rainy season commences in the 24th SMW and ends by 40th SMW. Isolated rainfall events are noted nearly all districts expect few discticts in the state during 50 to 20 SMW and the rains get momentum with the onset of monsoon from 22 SMW onwards.About 353 taluks in the state spread in *Marathwada, Madhya Maharashtra and Vidharbha* region, 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 Ahmednagar, Dhule, Jalgaon, Sangli, Satara, Solapur, Aurangabad, Jalna, Latur, Osmanabad, and some talukas of Parbhani, Nanded, Buldhana, Amravati and Nashik districts. Lowest annual rainfall is expected (at 75 per cent probability) in Ahmednagar district and also in some pockets of Dhule, Solapur, Sangli districts.

Moderate drought with probability of 10 to 20 per cent occurs in Jalna, Nashik, Buldhana, Akola, Beed, Aurangabad, Palghar, Ratnagiri, Raigadh, Thane, Solapur, Nanded, Jalgaon, Dhule and Kolhapur

districts. In fact, less area in the state has 20 and 30 per cent probability of the occurrence of moderate drought. Lowest probability is observed in Phulambri *taluka* of Aurangabad district and highest probability is observed in Bhoom and Kalamb *talukas* of Osmanabad district (58%). Around 80 per cent of the *talukas* 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 *talukas* of Ahmednagar, Jalgaon, Dhule and Akola districts. Highest severe drought probability is seen in Pune (18 %), Chandrapur, Yavatmal (13 %) and *talukas* of Sangli and Solapur, (11%).

Probability for near normal Southwest monsoon is above 50 per cent for all 328 *talukas*. Probability of 70% and above for near normal conditions is noted in nearly all *talukas* of Maharashtra (323 out of 328). In the case of moderately dry category, highest probability of 28% and above of rainfall is noted in two *talukas*. Probability occurrence of severely and extremely dry condition is observed in 248 and 178 *talukas*, respectively. However, probability of occurrence of severely dry conditions is highest (16%) in Lakhani and Karanja *talukas in* Bhandara and Washim district respectively and the probability of extremely dry condition is highest (26%) in Kalmeshwar, Kuhi, Katol and Mauda *talukas* of Nagpur district.

Probability for near normal conditions is above 50% during the post monsoon season in all the 328 *talukas* studied. *Severely and extremely dry conditions were not noted in 208 talukas and 235 talukas, respectively. Highest probability (11%) for severely dry category is observed in Hinganghat taluka of Wardha district and extremely dry (8%) in Kalmeshwar taluka of Nagpur district*.

Length of Growing Period (LGP)

The LGP stretches between 120-150 days in the districts of *Marathwada,* some districts of *Vidharbha* and *Madhya Maharashtra* region. LGP of > 180 days is observed in Raigadh, Thane and Ratnagiri districts. It is in the range of 150 to 180 days in parts of Kolhapur, Satara, Nashik, Solapur, Gadchiroli, Gondia, Chandrapur and Bhandara districts.

Growing season terminates early in most of the *Marathwada and Madhaya Maharashtra* districts (in 43 to 51 SMW) and (in 43 to 52 SMW) respectively compared to coastal *Kokan* districts (in 44 to 56 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 *Kokan* districts (22 weeks) followed by *Marathwada, Madhaya Maharashtra* and *Vidhabha* region (18 weeks) for soils having water holding capacity (WHC) of 50 mm. The corresponding figures for soils having 100 mm WHC are 25, 20, 20 and 20 respectively. For soils having 150 mm WHC the average duration for coastal, *Kokan* and *rest of regions* districts are 28 and 22 respectively. In soils having 200 mm WHC, the length of growing season is 31 and 24 weeks in Coastal *Kokan* and *rest of regions* districts, respectively. While soils having 250 mm water holding capacity, the length of growing season is 34, 26, 25 and 26 weeks in Coastal *Kokan, Madhaya Maharashtra, Mar*athwada and *Vidhabha* districts, respectively.

b) Other climatic elements

The mean annual temperature of the state is 32.8°C. A peak occurs during summer season (38.1°C) and the lowest is recorded during winter (30.9°C). Average temperatures are ± 31.3°C during

SWM season and ±31.0°C during post monsoon season. Regionally the mean annual temperature is higher in Vidarbha (33.1°C), followed by *Konkan* (33.0°C), *Marathwada* (32.9°C) and *Madhya Maharashtra* (32.3°C). *Konkan* region experiences relatively low temperatures during SWM and summer seasons but higher temperatures during post monsoon and winter seasons compared to the three other regions of the state. Highest temperatures (>34.0°C) are recorded at Kudal in the southern most district of Sindhudurg and northerly Jalgaon.

The state as a whole experiences a minimum temperature of 19.2°C on an annual basis. However, there are regional differences. The highest annual mean minimum temperature is recorded in Vidarbha (19.8°C) and the lowest in Madhya Maharashtra (18.5°C). Among locations, Latur in *Marathwada* records highest annual minimum temperature of 21.7°C while Padegaon in *Madhya Maharashtra* records the lowest (16.8°C). On a monthly basis, state as a whole experiences high morning humidity during August (88%) and least humidity is during April (59%).

The mean annual wind speed for the entire state is 6.0 kmph with *Madhya Maharashtra* region recording highest average speed of 7.4 kmph. Coastal region is relatively calm with an average speed of 3.7 kmph. June is the month with high wind conditions for the entire state (9.3 kmph). Mean annual number of hours of bright sunshine for the state are 7.2 hrs/day with *Marathwada* (7.8 hr/day) receiving sunlight for a longer period. Parbhani (8.5 hr/day) in is the brightest location and Karjat (6.2 hr/day) is the dimmiest. April month month has longest days (9.5 hr/day) and July shorter day length (3.0 hr/day). Igatpuri receives sunlight for the shortest period of 0.7 hr/day in the month of July.

Average total annual evaporation in the state is 2191mm. Evaporation in the *Marathwada* region is the highest (2451 mm) and it is lowest over *Konkan* region (1456 mm). Akola ranks first with an annual evaporation of 2739 mm and least in Kudal (1427 mm). May month records maximal evaporation. The mean total evaporation for the month of May is 332 mm for the entire state with highest recorded in Akola (503 mm) and the in Kudal (171 mm).

c) Agrometeorological production constraints and opportunities

In the entire Maharashtra, scarcity of water is a critical limitation for adoption of modern technologies for increasing productivity of traditional *paddy* growing areas. Use of hydrological models coupled with seasonal rainfall forecast helps 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 rainfall data aids in the design, development and maintenance of appropriate drainage systems in the agricultural regions.

In the cotton growing tracts of Maharashtra, 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 pests and diseases 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, cotton sensitive to high humidity causing boll rot therefore prophylactic measures could be taken up if timely and precise agromet advisories are issued.

Information on high probability of break in monsoon conditions in grain legume growing areas can assist in developing agromet advisories on intercultural operations, thinning 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, even late in the season. In areas sensitive to water logging conditions, advisories on the likely incidence of rainfall help in saving the crops.

Seasonal agromet advisories are of great assistance in the process of selection of appropriate cultivars of soybean and other oilseed crops. If onset of monsoon is delayed or sufficient rains are not received till July, alternate crops to soybean 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 case of sugarcane, its yields are affected by both the deficit or excess moisture 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, fit the crop is subjected to it water logging it affects the sucrose content, decreasing the recovery of sugar. High winds lodge the crop which depresses juice sucrose and cane weight. All these field problems can be addressed by proper and timely dissemination of agromet advisories.

1. General Information

1.1 Introduction

Maharashtra abids the western and central part of the country and has a long coastline stretching nearly 720 kilometers along the Arabian Sea. The Sahyadri mountain ranges provide a physical backbone to the State on the west, while the Satpura hills along the north and Bhamragad-Chiroli-Gaikhuri ranges on the east serve as it's natural borders. The State is surrounded by Gujarat to the North West, Madhya Pradesh to the north, Chhattisgarh to the east, Telangana to the south east, Karnataka to the south and Goa to the south west. Maharashtra State has a geographical area of 3,07,713 sq. km and is bounded by North latitude 15°40' and 22°00' and East Longitudes 72°30' and 80°30'.

The Western Ghats hill ranges run north to south separating the coastal districts of Thane, Mumbai, Raigad, Ratnagiri and Sindhudurg from rest of the State. The average height of these ranges is about 1000 m AMSL and form an important climatic divide. Maharashtra has a tropical monsoon climate, with hot, rainy and cold weather seasons. March to May is the summer season followed by rainy season from June to September. The post monsoon season is October and November. December to February is the winter season. The state has humid to per humid type climatic type in Konkan and Western ghats, semi arid type in central and western Maharashtra, and sub humid type in the eastern part of the state. The maximum and minimum temperature varies between 27°C and 40°C & 14°C and 27°C respectively. The maximum summer temperature varies between 36°C and 41°C and during winter the temperature oscillates between 10°C and 16°C. Rainfall starts in the first week of June and July is the wettest month. Rainfall in Maharashtra differs from region to region. The State experiences extremes of rainfall ranging from 6000 mm over the Ghats to less than 500 mm in the rain shadow semi arid areas of western and central Maharashtra. The Konkan sub-division comprising of coastal districts and Western Ghats receive the heaviest rains, the Ghats receive more than 6000 mm and the plains 2500 mm. Rainfall decreases rapidly towards eastern slopes and plateau areas where it is minimum (less than 500 mm). It again increases towards east i.e. in the direction of Marathwada and Vidarbha and attains a second maximum of 1500 mm in the eastern parts of Vidarbha. Thus, Madhya Maharashtra sub-division is the region of the lowest rainfall in the State.

1.2 Land use pattern

Land is the basic resource for agriculture. Its quality and extent largely determine the variety and magnitude of agriculture production. The land utilisation statistics for 2015-16 depicts that out of the total 307.58 lakh ha geographical area of the State, the gross cropped area was 228.6 lakh ha while the net area sown was 171.92 lakh ha. The forested area was 51.95 lakh ha which is distributed in the western, northern and the eastern zones having relatively heavy rainfall in the state. The land not available for cultivation was 32.52 lakh ha, other uncultivated land was 23.87 lakh ha and fallow land was 27.32 lakh ha. During the period of five years from 2011-12 to 2015-16, land put to non-agricultural uses has increased by 4.9 per cent. The time series data of land utilisation is given in Table 1.

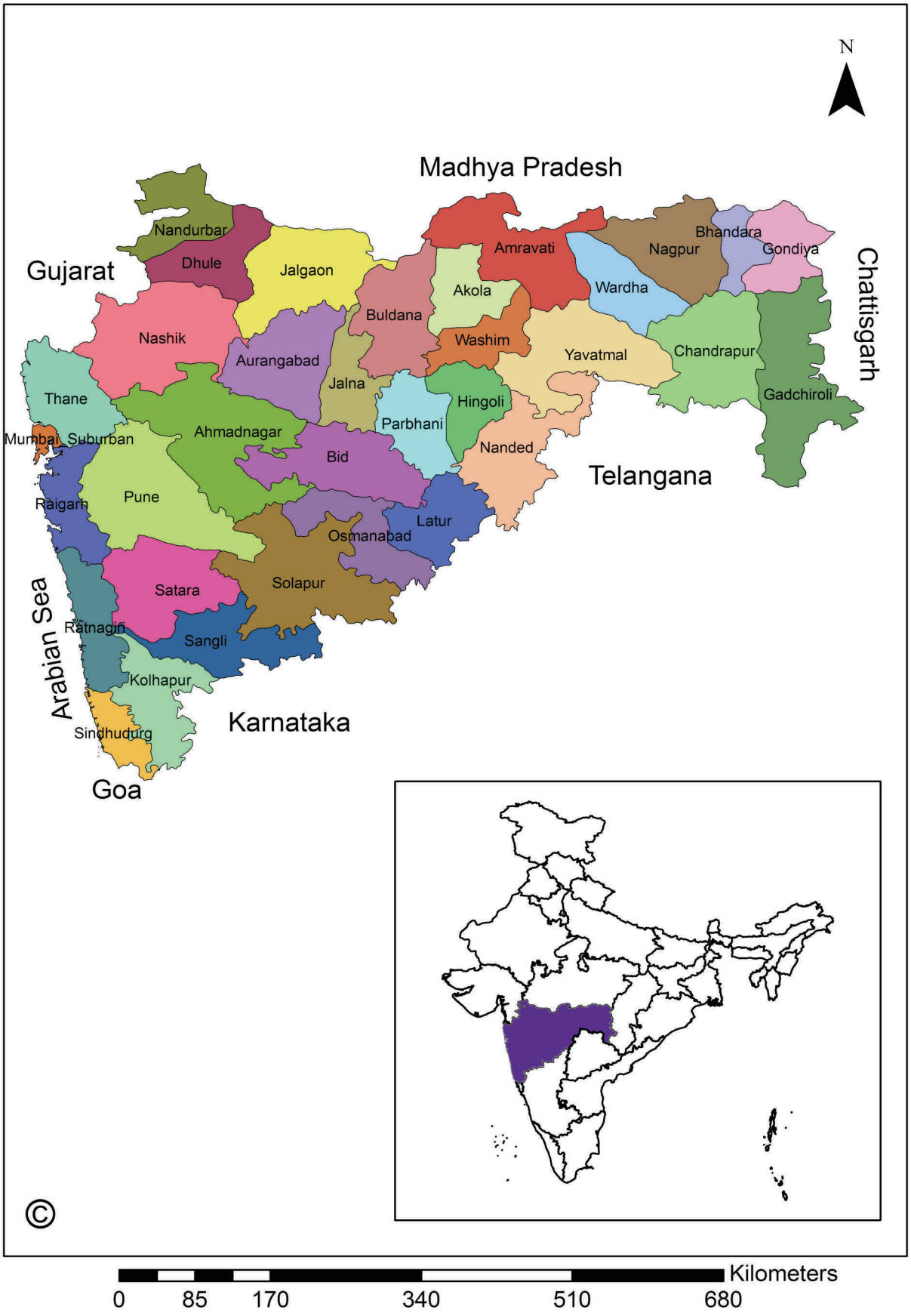


Fig. 1 : Map of Maharashtra with district boundaries

Table 1 : District wise land utilisation statistics of Maharashtra (Area in '00' ha)

Year	Area under forests	Land not available for cultivation		Other uncultivated land			Fallow lands		Cropped Area		
		Barren and uncultivable land	Land put to non-agricultural uses	Culturable waste land	Permanent pastures and grazing land	Land under miscellaneous tree crops and groves	Current fallows	Other fallows	Net area sown	Double cropped area	Gross cropped area
1986-87	5350	1679	1152	1044	1367	196	909	1057	18004	2320	20324
1990-91	5128	1622	1091	966	1125	301	898	1063	18565	3295	21859
1995-96	5148	1544	1349	960	1166	292	1072	1248	17980	3524	21504
2000-01	5150	1544	1364	959	1168	327	1126	1276	17844	3775	21619
2001-02	5150	1544	1368	959	1168	327	1717	1303	17222	3769	20991
2002-03	5150	1544	1371	958	1168	328	1736	1308	17195	3720	20915
2003-04	5214	1725	1390	917	1249	251	1364	1216	17432	4758	22190
2004-05	5213	1726	1393	918	1251	249	1316	1204	17490	4878	22368
2005-06	5212	1720	1407	914	1252	249	1327	1204	17473	5083	22556
2006-07	5213	1719	1412	915	1252	249	1324	1196	17478	5079	22557
2007-08	5213	1718	1427	916	1248	248	1327	1188	17473	5182	22655
2008-09	5213	1718	1433	918	1246	248	1372	1188	17422	5032	22454
2009-10	5214	1729	1443	917	1242	250	1373	1189	17401	5211	22612
2010-11	5216	1731	1449	919	1242	250	1366	1179	17406	5769	23175
2011-12	5211	1728	1450	919	1244	250	1378	1192	17386	5720	23106
2012-13	5207	1722	1456	916	1245	250	1418	1200	17344	5772	23116
2013-14	5206	1724	1460	915	1242	249	1401	1192	17368	6012	23380
2014-15	5201	1727	1482	919	1249	249	1399	1188	17345	5929	23273
2015-16	5195	1731	1551	887	1249	251	1477	1255	17192	5672	22863

Source - Commissionerate of Agriculture, GoM

Note -Figures for the years 2003-04 to 2011-12 are provisional.

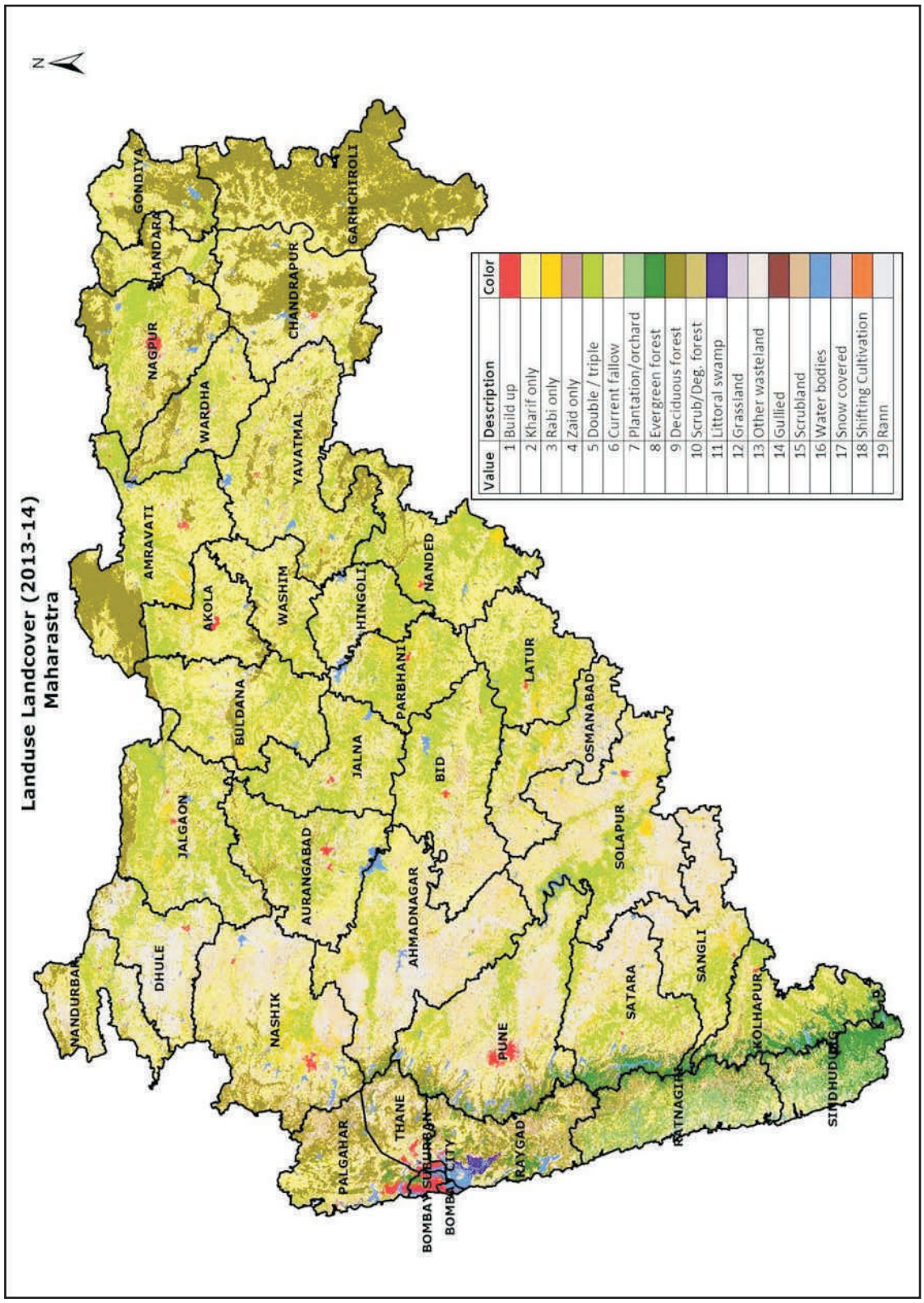


Fig. 2 : Land utilization pattern of Maharashtra

1.3 Distribution of soil types

The soil status of Maharashtra is residual, derived from the underlying basalts. In the semi-dry plateau, the *regur* (black-cotton soil) is clayey, rich in iron and moisture-retentive, though poor in nitrogen and organic matter. When re-deposited along the river valleys, the kali soils are deeper and heavier, better suited for *Rabi* crops. Farther away, with a better mixture of lime, the *morand* soils form the ideal *Kharif* zone. The higher plateau areas have *pather* soils, which contain more gravel. The soils of Maharashtra region belong to Entisol, Inceptisol, Alfisol, Vertisol and Mollisol orders. It has been observed that Entisols(36.8%), Inceptisols(30.9%) and Vertisols(26.3%) are the predominant soils followed by Alfisols (5.6%) and Mollisols (0.1%)(Challa *et al*, 2001).

1.4 Soil depth

The depth of soil primarily helps plant growth for foot hold and spread of root system and it regulates nutrients and water storage and supply. Thus, it is a good indicator of water and nutrient supplying potential of soil. Based on its applications towards the crop growth, six depth classes are formed (Table 2) The district wise area under different soil depth categories is given in Fig.3.

Table 2 : Soil depth classes

Class	Area ('000'ha)	%
Extremely shallow (<10cm)	1885.3	6.1
Very shallow (10 to 25 cm)	8127.2	25.4
Shallow (25 to 50 cm)	4444.2	14.4
Slightly deep (50 to 75 cm)	4683.5	15.3
Moderately deep (75 to 100 cm)	1354.1	4.4
Deep (> 100 cm)	10274.6	33.4

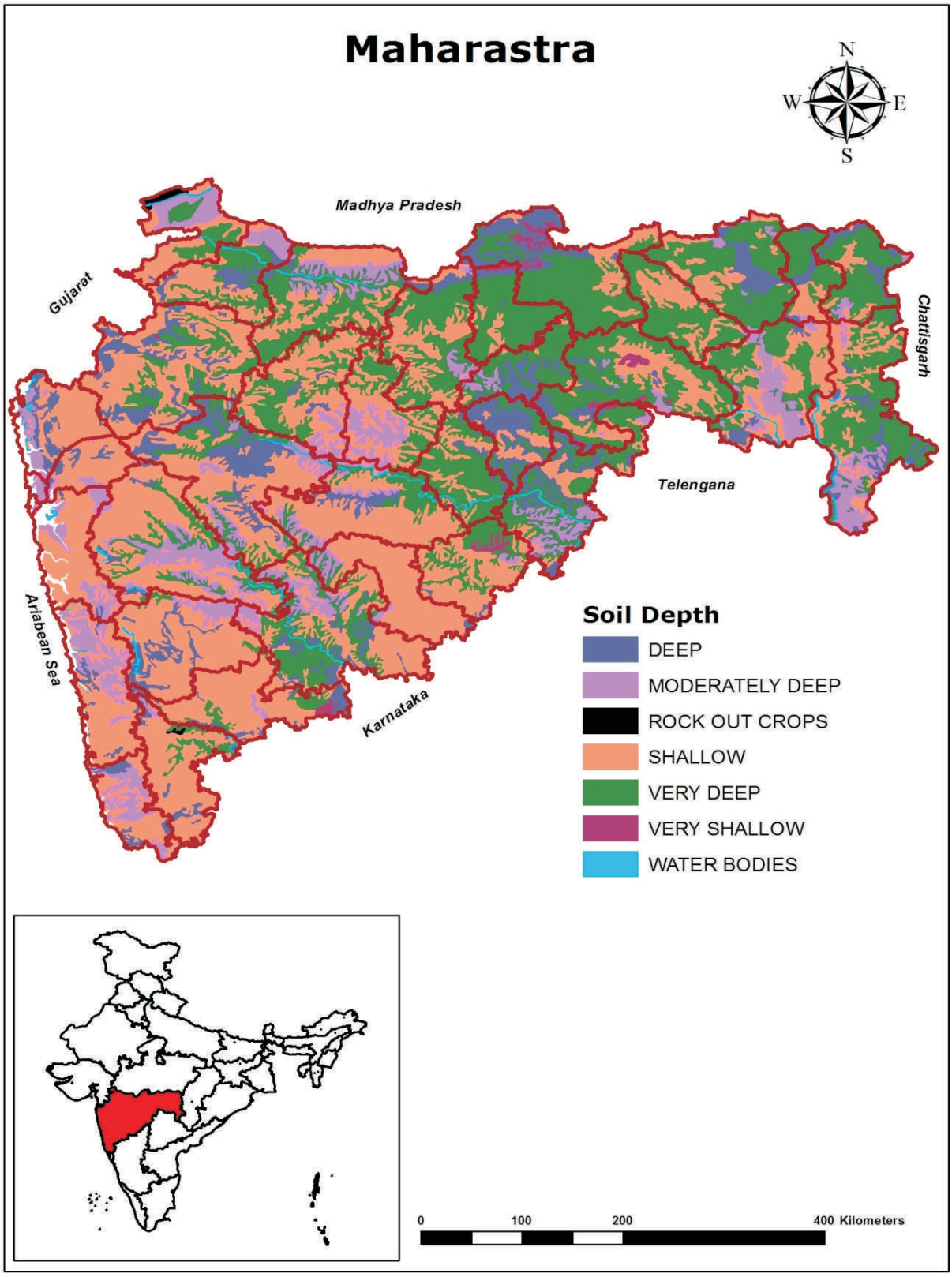


Fig. 3 : Soil depth (cm) map of Maharashtra (Source - NBSSLUP Nagpur)

1.5 Soil drainage

Soil drainage both surface and subsurface, influence soil-air-water relationship, affects the oxygen availability, the redox potential and nutrient availability. Since the root proliferation is related to aeration, the drainage can form a limiting criteria for evaluating soil suitability for annual as well as the perennial crops including forest species. The drainage condition has been classified into six drainage classes. The extent of the area under each class is given in Table 3 and Fig 4. Majority of the soils in the state are well drained, followed by moderately well drained class showing good aeration to plant roots. Somewhat excessive and excessively drained soils occur at higher topography. Poorly drained soils are in traces as scattered patches near creeks.

Table 3 : Soil drainage classes

Class	Area ('000'ha)	(%)
Poor	164.6	0.5
Imperfect	8.9	Negligible
Moderately well	10603.9	35.7
Well	14523.9	49.2
Somewhat excessive	3094.0	10.4
Excessive	1263.8	4.2

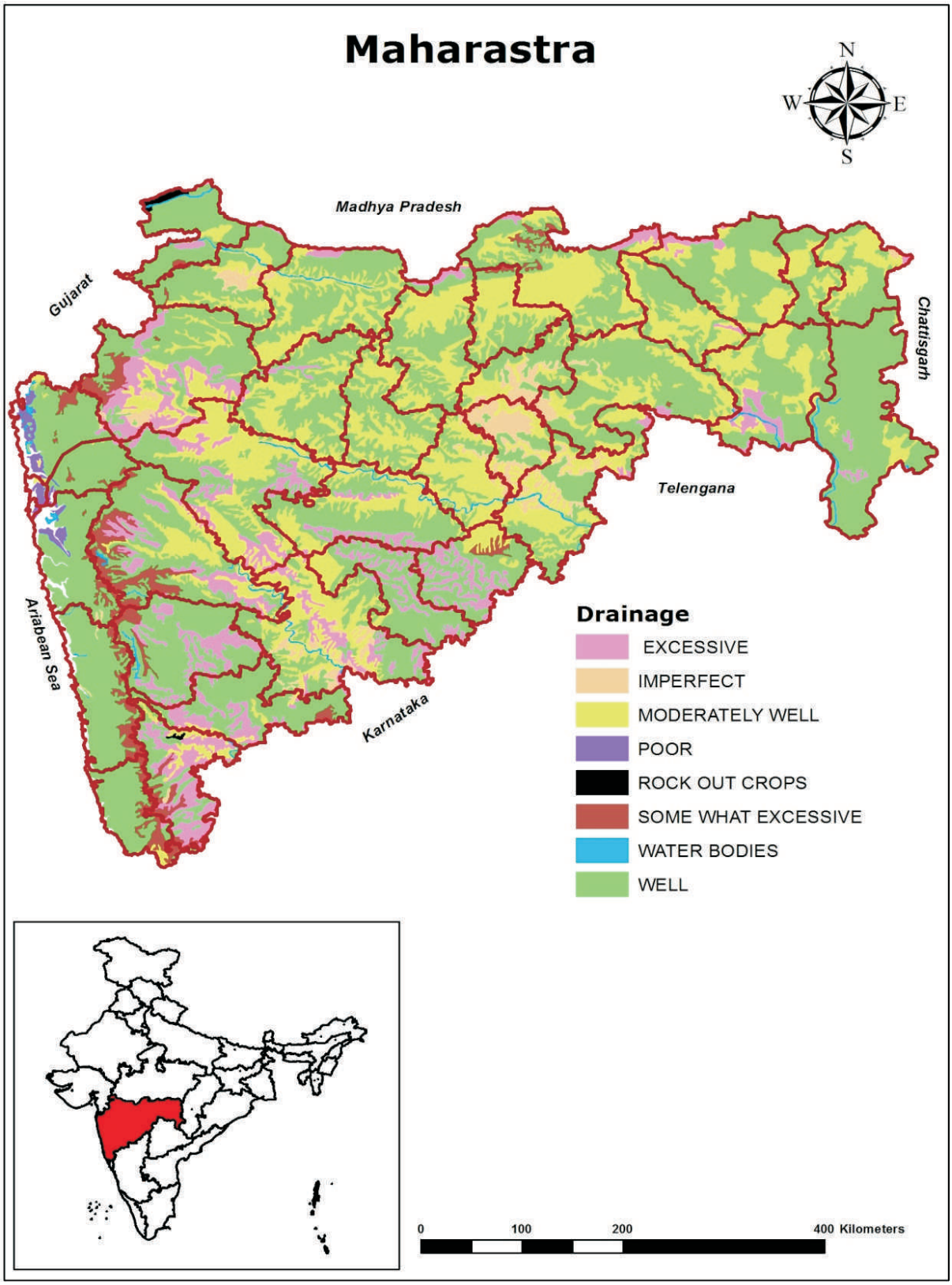


Fig. 4 : Soil drainage map of Maharashtra (Source - NBSSLUP Nagpur)

1.6 Soil pH

Soil reaction is a physico-chemical property which influences the availability of different plant nutrients. It is measure of acidity and alkalinity and reflects the base saturation. Soil pH value assumes importance in determining the amendments used for amelioration of soils. Soil reaction in the state ranges from moderately acidic class to slightly alkaline class (Table 4). The soils developed on alluvium parent material have a pH in neutral range and are dominant in montmorillonite minerals. The acid soils are developed from granite and sandstone and are dominant in kaolinite minerals.

Table 4 : Soil reaction (pH) classes

Class	Area'000'ha	(%)
Moderately acidic (4.5 to 5.5)	516.6	1.7
Slightly acidic (5.5 to 6.5)	5145.0	16.7
Neutral (6.5 to 7.5)	14928.5	48.5
Slightly to moderately alkaline (7.5 to 8.5)	10178.9	33.1

1.7 Soil slope

The length and gradient of slope affect the soil formation and soil depth in an area. It also affects the water retention and infiltration. Seven slope classes have been observed which is given in Table 5. The slope of soil is related to elevation and determines soil depth, degree of erosion, texture and pH. About 76.4 per cent of the area in the state falls under very gently (39.5%) and gently sloping (36.9%), usable for aerable lands. The major area in the state is below 1-3% slope. Across the districts, slope conditions vary (Fig 5).

Table 5 : Slope classes

Class	Area ('000' ha)	(%)
Level to nearly level (0 to 1%)	113.0	0.4
Very gently sloping (1 to 3%)	12114.9	39.5
Gently sloping (3 to 8%)	11384.2	36.9
Moderately sloping (8 to 15%)	4182.9	13.6
Moderately steep sloping (15 to 30%)	2550.8	8.3
Steeply sloping (30 to 50%)	159.6	0.5
Very ste ep sloping (>50%)	263.6	0.8

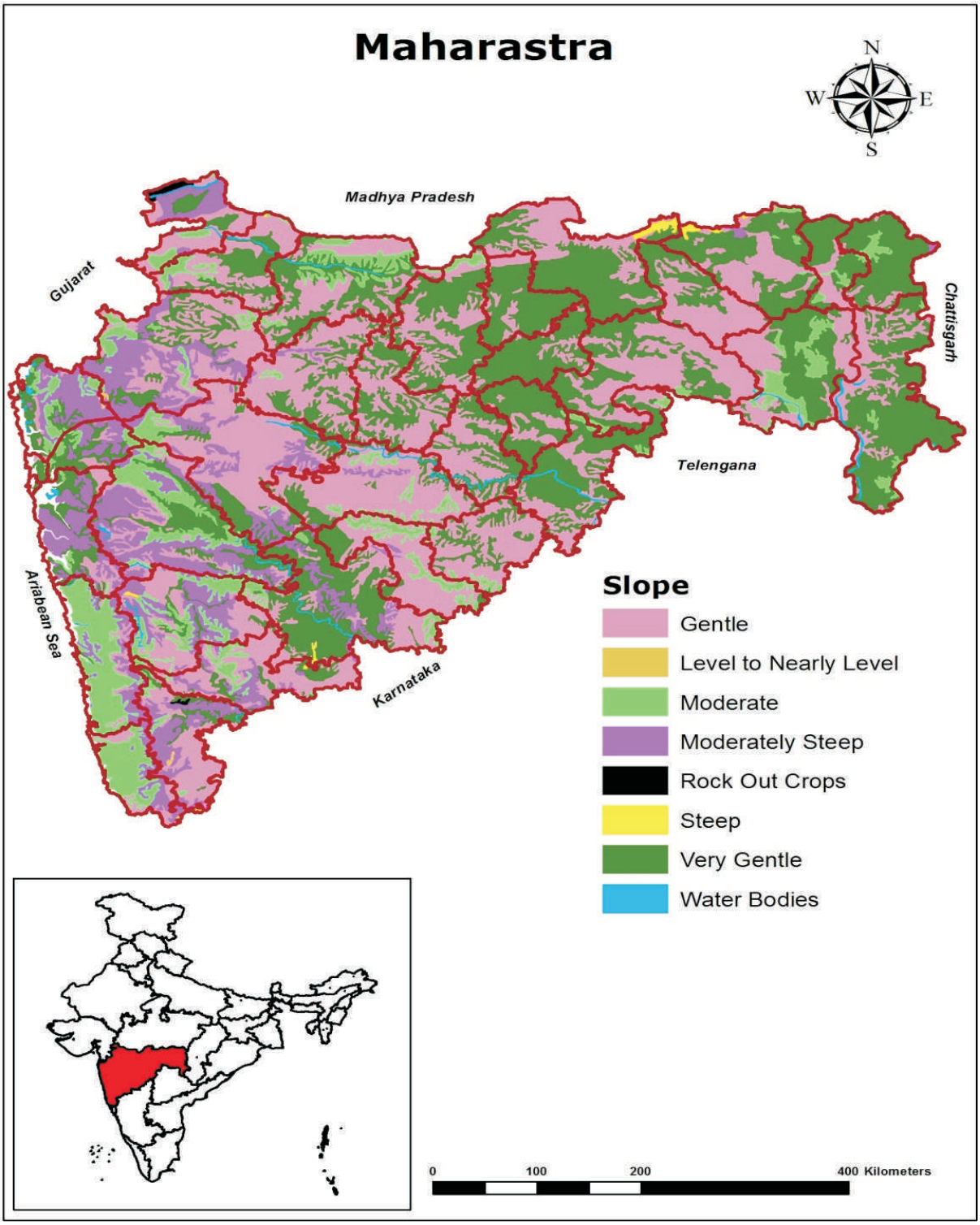


Fig. 5 : Soil slope map of Maharashtra (Source - NBSSLUP Nagpur)

1.8 Land surface

Surface form is the resultant of the present and past climate in the area under natural conditions. Land surface tends to change with the human intervention resulting in denudation of the terrain. Land surface area is related to elevation and determines of geographical and surface distribution like as land slope, texture, plain, plateau and vegetation. The major area in the state is undulating (10.89 M ha, 35.4%) followed by valley land. Among the districts, slope conditions are of different categories.

- Valleys and dissected
- Gently sloping & valleys
- Hummocky and valleys
- Plateau
- Ridges
- Undulating and dissected
- Valleys
- Gently sloping
- Hummocky
- Level
- Plateau dissected
- Undulating
- Undulating and valleys

1.9 Soil texture

Soil texture indicates the relative proportion of primary particles, such as sand, silt and clay. It is a permanent physical characteristic and directly related to structure, porosity adhesion and consistency. It affects the microbial activity and physico-chemical behavior of the soils thus influencing plant growth directly or indirectly. It influences the water storage, nutrient holding, workability, infiltration and drainage conditions. The soils are dominantly clayey in texture (61.1%) in the region followed by loamy (38.9%). Clayey textures have high potential for nutrients and available water holding capacity. The area under different texture classes is given in Fig. 6.

1.10 Soil erosion

The degree of erosion determines the suitability of a soil for agricultural use. It is an indication of how proper is the current land use and also determines the kind of management needed in a terrain for improving the land. As per the intensity , the erosion has been categorized into sheet , rill and gully erosion. Mere referring soil erosion does not convey purposeful meaning. It should be linked with the potential productivity of soil to evaluate its permanent effect. Improved management practices, besides controlling the erosion improves productivity and reduces the degradation. Soils in the state are grouped into four soil erosion classes (Table 6) namely slight, moderate, severe and very severe class. Majority of the area is under moderately eroded class (66.4%) followed by severe class (27.4%). The area under slight class is 4.2 per cent and that of very severe class is 2.0 per cent. Area under slight to moderately eroded classes have somewhat reduced agricultural productivity to greatly reduced (but economical) agricultural productivity. While severe and very severe classes are un-reclaimable and economically not feasible to reclaim

Table 6 : Soil erosion classes

Class	Area ('000'ha)	(%)
Slight	1278.0	4.2
Moderate	20448.0	66.5
Severe	8441.1	27.3
Very severe	601.1	2.0

1.11 Available Water Capacity

Available water capacity of the soils is dependent upon the intensity and distribution of rainfall, infiltration and permeability of the soils and type and amount of clay minerals, depth and volume of the soil. In the dry tract, the quantum and the regular soil moisture supply (available water) act as determinants for growing crops. This also helps in deciding the length of growing period (LGP) which is important parameter for crop planning in an area where the crops are grown under rainfed conditions. Based on the AWC, soils in the state are grouped under 5 classes. The extent of area under different classes are given in Table 7 and Fig 7.

Table 7 : Available water capacity (AWC) classes

Class	Area ('000' ha)	(%)
Very low (<50 mm)	10643.9	34.7
low (50-100 mm)	4529.1	14.7
Moderate (100-150 mm)	3510.1	11.4
High (150-200 mm)	1140.9	3.7
Vey high (>200mm)	10698.6	34.8
Miscellaneous lands	236.4	0.7

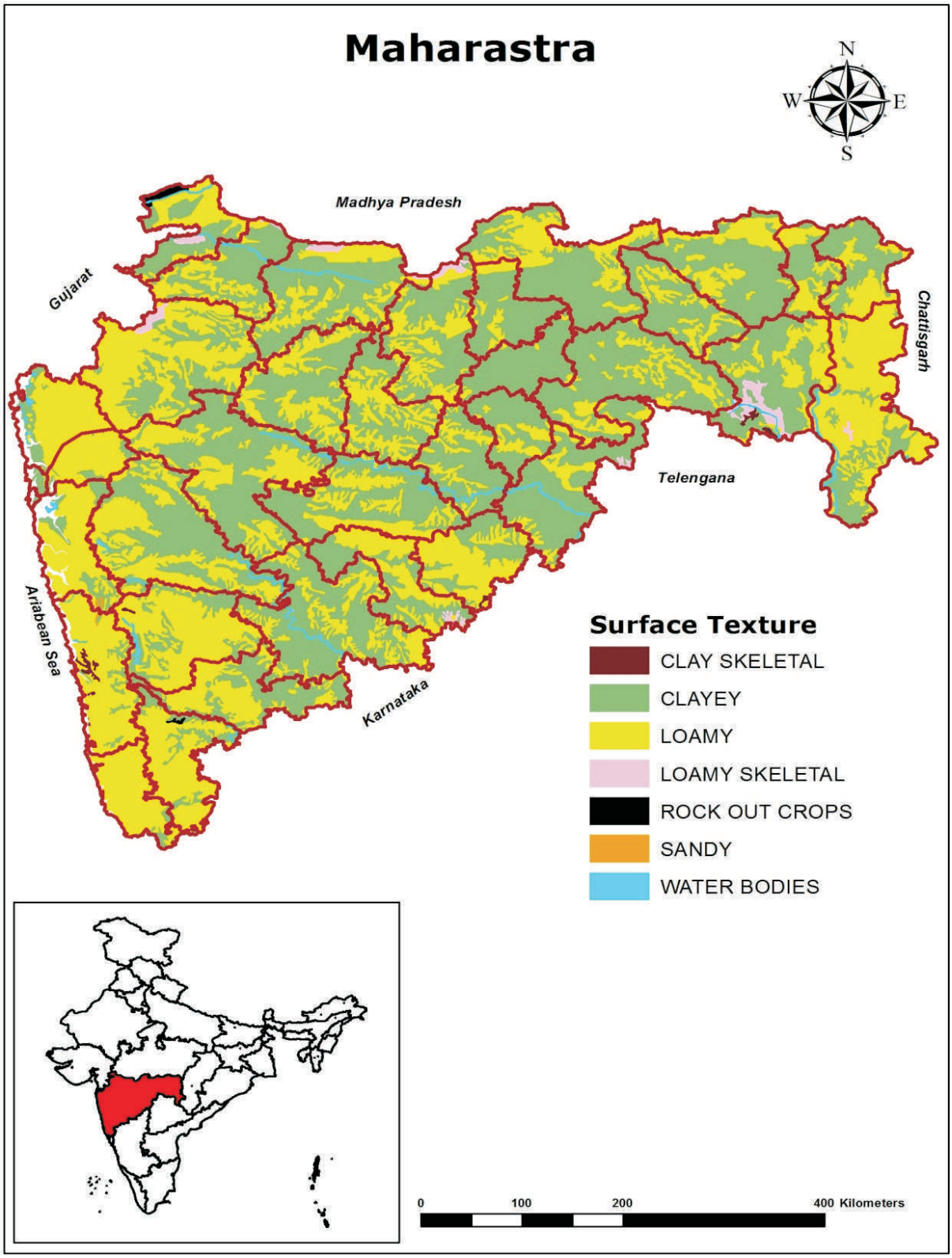


Fig. 6 : Soil texture map of Maharashtra (Source - NBSSLUP Nagpur)

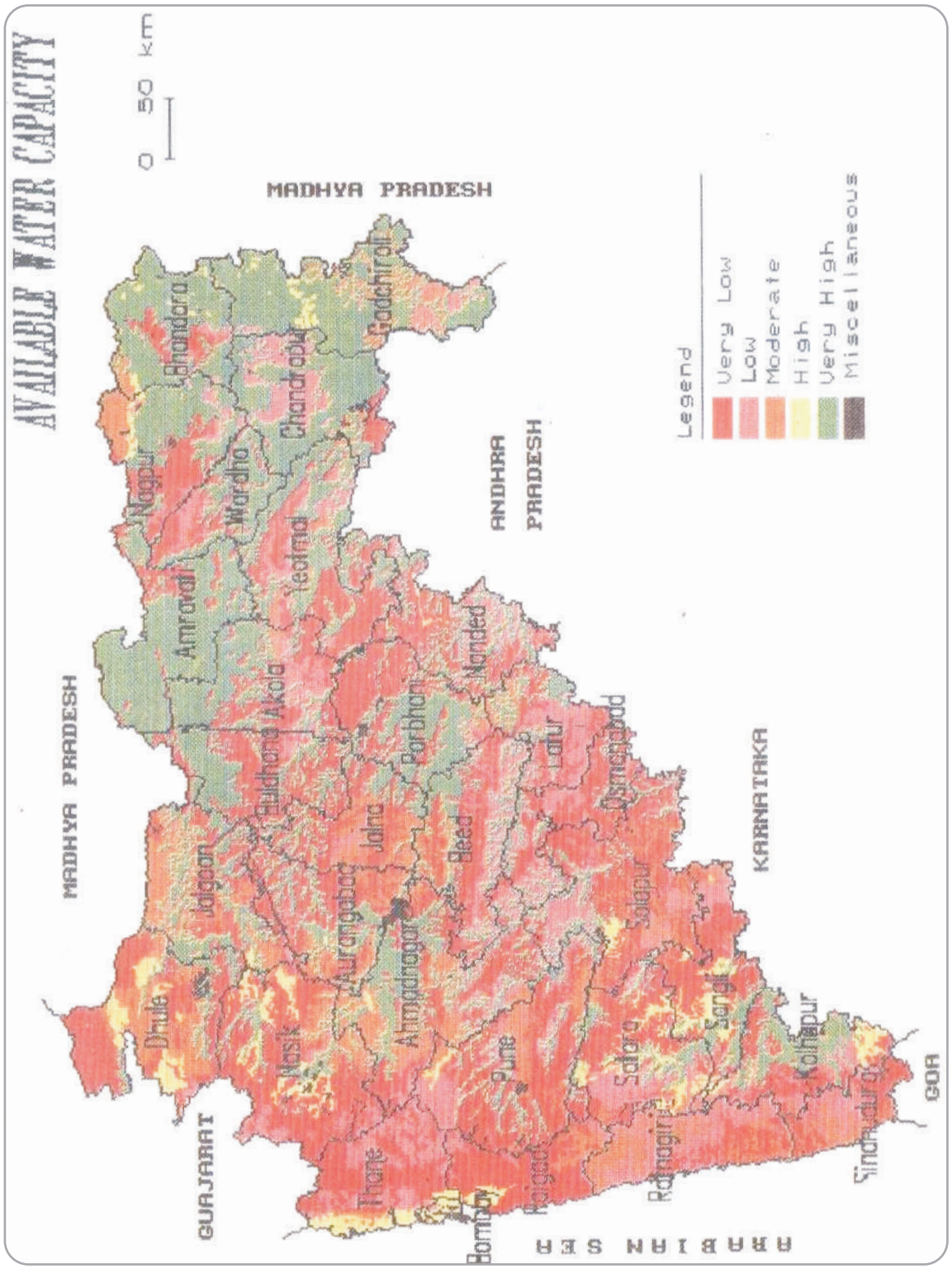


Fig. 7 : Available Soil Water Content (mm) map of Maharashtra (Source - NBSSLUP Nagpur)

2. Agro-Climatic Features of Maharashtra

2.1 Introduction

The identification of agro-climatic zones for the purpose of developing location specific research and development strategies for increasing agricultural production has been given the due impetus recently. Planning Commission , Government of India has identified 15 agro-climatic zones in the country primarily based on geographical basis for development purpose. Subsequently, the concept of homogenous agro-ecological zones was initiated by the ICAR in 1979 under the National Agricultural Research Project (NARP) and the country was divided into 127 zones under NARP . There zones to a large extent have homogenous physical characteristics such as topography, rainfall, soils, cropping patterns and irrigation availability. Of the total 127 NARP zones, 73 are predominantly rainfed. While delineating zonal boundaries, the physiographic divisions of each state, its rainfall pattern, soil type, availability of irrigation water, existing cropping pattern and administrative units have been considered in such a manner that there are fewer variations on the parameters within a zone (Rao *et al.,* 2013). There are nine agroclimatic zones under NARP in Maharashtra based on the broad criteria of rainfall, topography, soils and cropping pattern.

2.2 Agro-climatic zonations of Maharashtra

In order to maximize the production from the available resources and prevailing climatic conditions, need-based, location specific technologies need to be generated. Delineation of agro-climatic zones based on soil, water, rainfall, temperature etc. is the first essential step for sustainable production. An "Agro-climatic zone" is a land unit in terms of major climates suitable for a certain range of crops and cultivars. The planning aims at scientific management of regional resources to meet the food, fiber, fodder and fuel wood without adversely affecting natural resources and environment. Agro-climatic conditions mainly refer to soil types, rainfall, temperature and water availability which influences the type of vegetation. With large dependence on rainfall, the cropping intensity of the state is around 128 percent. Agro-climatic features of various zones in Maharashtra are given in Table 8.

Table 8 : Agro-climatic features of various zones in Maharashtra

Sr. No.	Name of the Zone	Geographical location	Geographical spread of the zone, districts and tehsils	Climatic conditions	Average annual rainfall	Soil type	Crop and cropping pattern
1. South Konkan Coastal Zone							
I	Very high Rainfall zone with laterite soils	15.30 to 18.50 N Latitude 72.45 to 74.50 E Longitude	Comprises mainly of Ratnagiri and Sindhudurg districtsTotal area of the zone is13.20 lakh ha and areaunder cultivation3.5 lakh ha.	Daily temperature above 20^0C throughouthe year. Mayhottest above 33^0C. Rainfall due to south west monsoonfrom June to Sept.	3105 mm 101 days	LateritePH 5.5-6.5 acidic,poor in phosphorous rich in nitrogen and Potassiu m	Rice is the major crop . Ragi 2nd important crop, vari is minor hill milletgrown on the slopes, pulses likehorsegram grown on residual moisture. Oilseeds- niger / sesamum,. Horticultural crops mango, coconut, arecanut, cashewnut, jackfruit, banana and pineapple, spices like clove nutmeg and black pepper
2. North Konkan Coastal Zone							
II	Very high rainfall zone with non-lateritic roils	17.52 to 20.20 latitude 70.70 to 73.48 E longitude	Comprises of Thane and Raigad districts. Total area 16.59 lakh ha. Net sown area 4.69 lakh ha . 32% of land is under forest.	Average. daily temp 22 to 30^0C. Minimum Temperature 17 to 27^0C. Humidity 98% in rainy season and 60% in winter.	2607 mm in 87 days. Maximum rains received in July (41%).	Coarse and shallow. PH 5.5 to 6.5. acidic Rich in nitrogen. Poor in phosphorus & potash.	Rice is major crop followed by Vari . Pulses- blackgram, pigeonpea Vegetables-brinjal, tomato. Oilseeds-sesamum, niger, Fruits-banana, sapota
3. Western Chat Zone							
III	Western Ghat Zone / Ghat zone	Narrow strip Extending from north to south along the crest of Sahyadri ranges	It includes hilly high lying terrains of Kolhapur. Satara. Pune. Ahmednagar & Nasik Districts and small area of Sindhudurg District.	Maximum temperature ranges from 29-39^0C. Minimum temperature ranges from 13- 20^0C.	3000 to 6000 mm rainfall recorded in different places of the zone viz., Igatpuri. Lonawala, Mahabaleshwar & Radhanagari	'Warkas ' *i.e.* light laterite & reddish brown. Distinctly acidic, poor fertility, low phosphorus & potash content	25% area is under forest. Principal crops- rice, ragi kodra and other cereals, *rabi* sorghum, chickpea, groundnut, niger. Sugarcane major crop.Area also under spices and vegetables. Well suited conditions for rainfed crops. Fruits-mango, cashew. jackfruit, jamun and karvanda.
4. Transition zone I							
IV	Sub Montane Zone/Transition Zone I	Located on eastern slopes of Sahyadri ranges	Spreads over 19 tehsils of five districts viz., Nasik. Pune. Satara, Sangli and Kolhapur. The area of the zone measures 10.289 Sq Km	Average maximum temperature is between 28-35^0C and minimum temperature 14-19^0C	700- 2500 mm. Rains received mostly from SW monsoon.	Soils are reddish brown to black tending to lateritic.PH 6-7. Well supplied in nitrogen but low in phosphorus & potash	Mainly dominated by *kharif* cereals, groundnut and sugarcane. Rabi crops are taken where there are deep soils. Vegetables-potato, onion, chillies, tomato and brinjal. Fruits- mango, banana, guava, cashew and grapes.

5.	**Transition Zone - II**						
V	Western Maharashtra Plain Zone/ Transition zone II	It is a wider strip running parallel to eastern side of Sub Montane Zone	This zone includes tehsils of Dhule, Ahmednagar, Sangli and central tehsils of Nasik, Pune, Satara and Kolhapur districts. Geographical area 17.91 lakh ha. Net area sown is 8.86 Lakh ha.	Water availability ranges from 120- I50 days. Maximum temperature 40^0C & minimum temperature 5^0C.	Well distributed rainfall 700 to 1200 mm.	Topography is plain. Soils greyish black. Moderately alkaline PH 7.4 - 8.4. Lowest layer is 'Murum' strata. Fair in NPK content. Well drained and good for irrigation.	The zone is predominantly a *kharif* tract suitable for single rainfed crop. Principal crops grown-*kharif* and *rabi* sorghum, pearlmillet, groundnut, wheat, sugarcane, blackgram, pigeonpea, chickpea and ragi.
6.	**Scarcity Zone**						
VI	Western Maharashtra Scarcity Zone/ Scarcity Zone	-	This zone covers geographical area of 73.23 lakh ha. The gross and net cultivated area is 58.42 ad 53.0 lakh ha respectively.	Suffers from very low rainfall with uncertainty and ill distribution. Occurrence of drought is noted once in three years. Dry spell varies from 2-10 weeks. Water availability 60- 140 days. Which is affected due to d delayed onset of monsoon and early cessation of monsoon. Maximum temperature 41^0C and minimum temperature 14-15^0C	Less than 750mm in 45 days. Two peaks of rainfall, 1. June/July 2. September. Bimodal pattern of rainfall.	General topography is having slope between 1-2%. Infiltration rate is 6-7 mm/hr. Soils are vertisols. Soils have montmorillonite clay. Poor in nitrogen, low to medium in phosphate and well supplied in potash.	Based on bimodal distribution of rainfall two cropping systems are noticed. During *kharif* shallow and poor moisture retentive soils are cultivated. Medium deep soils are diverted to rabi cropping. Kharif cropping 25-30%. Crops - pearl millet, sorghum, groundnut, safflower, pulses etc. Productivity is rather low in both the seasons.
7.	**Assured Rainfall Zone**						
VII	Central Maharashtra Plateau Zone /Assured Rainfall Zone	-	Comprises parts of Aurangabad, Jalna, Beed and Osmanabad districts. Major parts of Parbhani and Nanded and, complete Latur, Buldhana and parts of Akola, Amravati, Yavatmal, Jalgaon, Dhule and Solapur. Area accounts to 75 lakh ha. Gross cropped area is 67.8 lakh ha. Forest accounts to 9.9 % of geographical area.	Maximum temperature 41^0C , Minimum temperature 21^0C	700 to 900 mm .	Soil colour ranges from black to red. Type- I) Vertisols 2) Entisols and 3) Inceptisols PH 7-7.5	Sorghum , cotton, oil seeds- groundnut, sesamum safflower and niger. Pulses - pigeonpea, greengram, blackgram, lentils and chickpea, Sugarcane & summer crops are taken on availability of irrigation.

8. Moderate Rainfall Zone							
VIII	Central Vidarbha Zone /Zone of Moderate Rainfall	There are five sub- zones of central Vidarbha zone based on climate soil & cropping pattern	The zone includes entire Wardha, major parts of Nagpur Yavatmal, 2 tehsils of Chandrapur and parts of Aurangabad, Jalna Parbhani and Nanded districts. Largest agro climatic zone encompassing 49.88 lakh ha geographical area and 35.73 lakh ha net cropped area.	Maximum temperature 33-38^{0}C. Minimum temperature 16-26^{0}C. Average daily humidity 72 % in rainy season, 53 % in winter and 35% in summer.	1130 mm	Black soils derived from basalt rock. Medium to heavy in texture, alkaline in reaction. Low lying areas are rich and fertile.	Cropping patterns involves Cotton, *kharif* sorghum, pigeonpea, wheat, other pulses and oilseeds
9. Eastern Vidarbha Zone							
IX	Eastern Vidharbha Zone/High Rainfall Zone with soils derived from parent material of different crops. There are four sub zone based on climate, soil and crop pattern.	-	Includes entire Bhandara and Gadchiroli, parts of Chandrapur and Nagpur districts. Geographical area is 32.7 lakh ha. With almost 50% under forest. Gross crop area 10.8 lakh ha.	Mean maximum temperature varies from 32 to 37^{0}C. Minimum temperature 15 to 24^{0}C. Daily humidity 73% for rainy season 62% winter and 35% summer.	950 to 1250 mm on western side. 1700 mm on extreme east side Number of rainy days 59.	Soils derived from parent rock granite, gneisses, and schists. Brown to red in colour. PH 6 to 7	Paddy is predominant crop in Bhandara, rabi pulses- chickpea, lathyrus. Paddy is followed by *rabi* sorghum pulses and oilseeds.

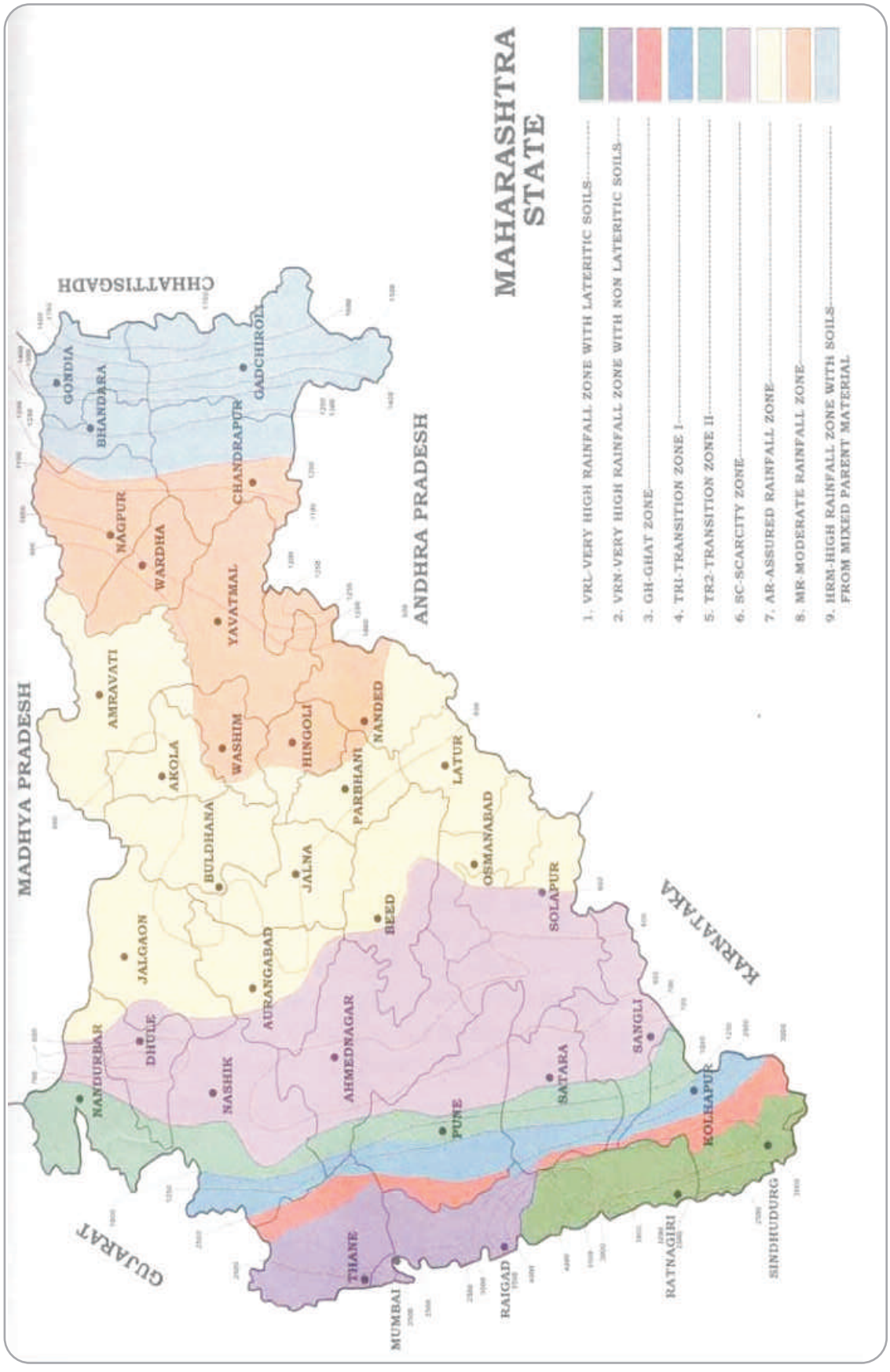


Fig. 8 : Agro-climatic zones of Maharashtra

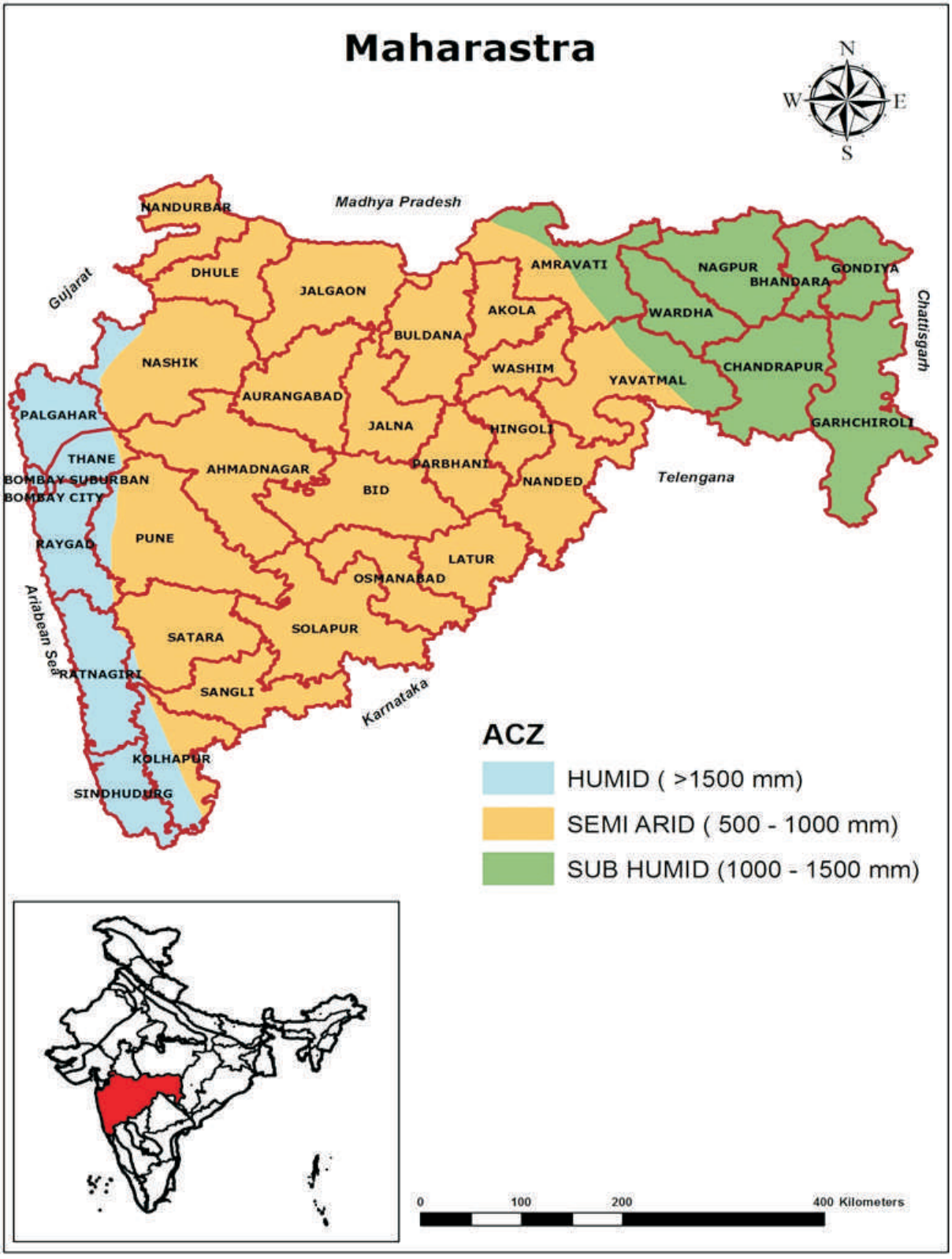


Fig. 9 : Agro-climatic zones of Maharashtra

(Source: NBSS & LUP)

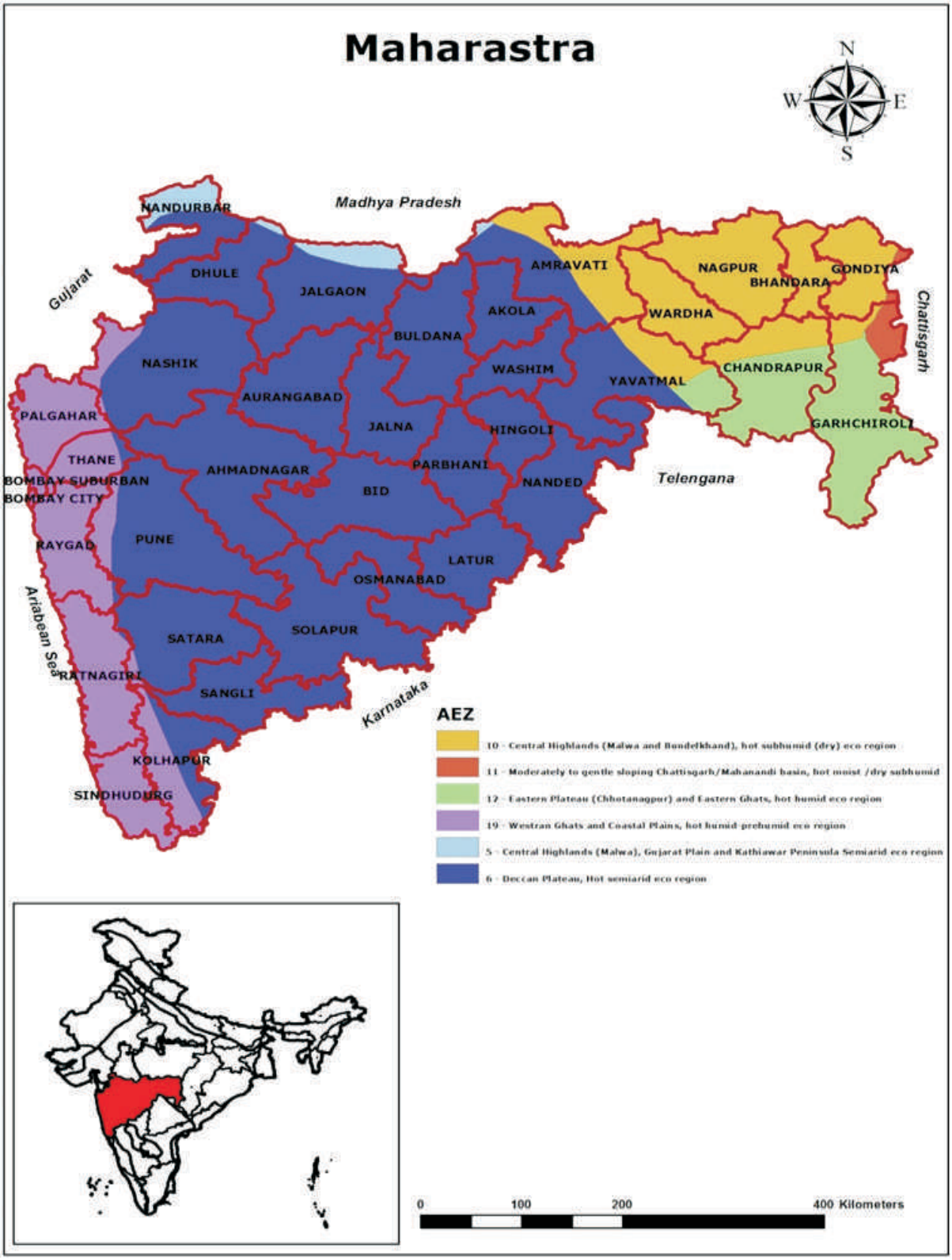


Fig. 10 : Agro-ecological regions of Maharashtra

(Source: NBSS & LUP)

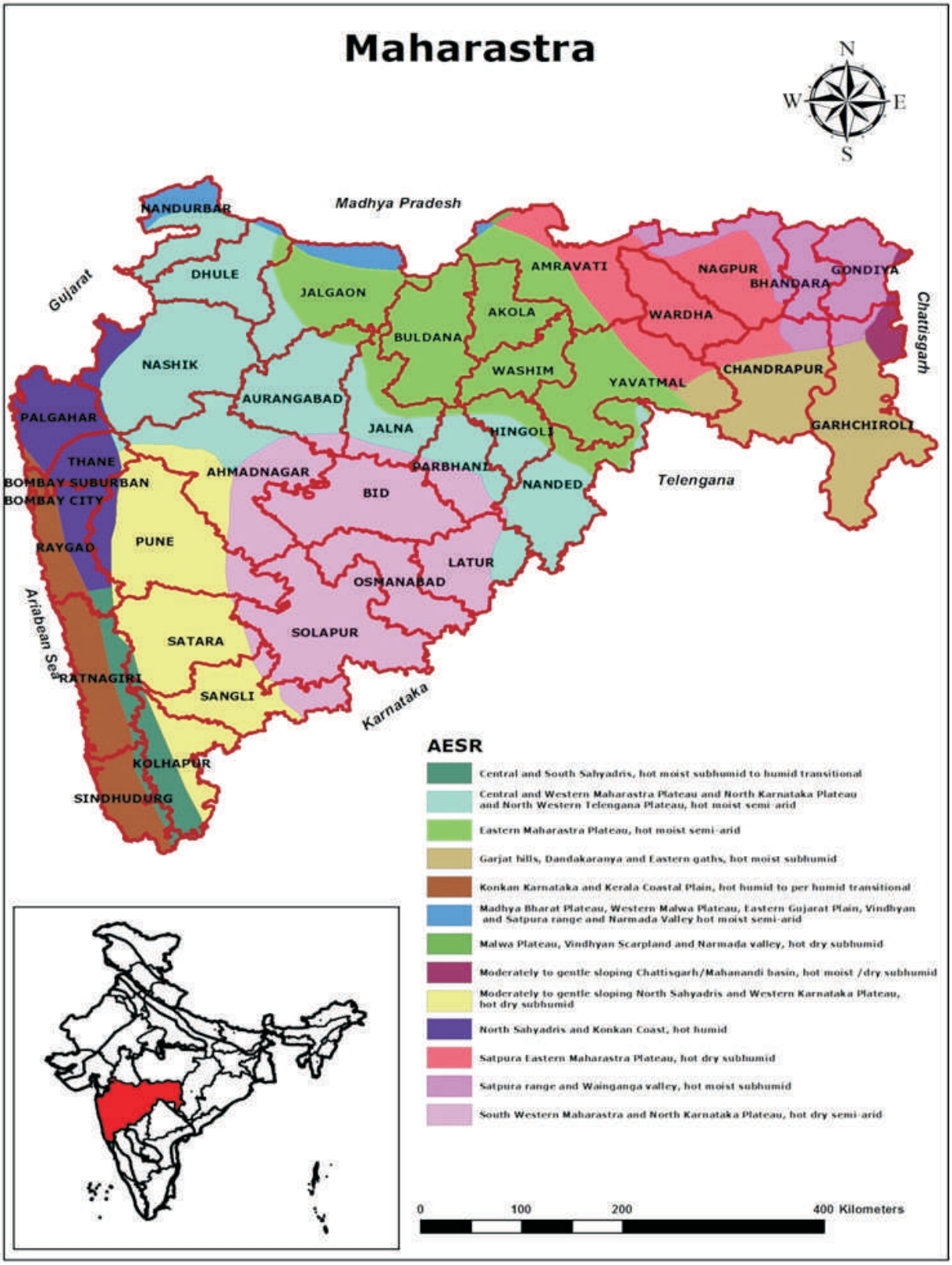


Fig. 11 : Agro-ecological sub regions of Maharashtra

(Source: NBSS & LUP)

2.3 Agro-ecological regions

National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur has come up with 20 agro-ecological regions (Sehgal *et al.,* 1992 and Sehgal 1995) for the country and 60 agro-ecological sub regions (AESR). The major criteria for the delineation of regions were (i) length of growing period as an integrated criterion of effective rainfall (ii) soil groups enjoy precedent over physiography (iii) deliniated boundaries adjusted to district boundaries (iv) number of regions as minimal as possible. Agro-ecological regions and agro-ecological sub-regions in Maharashtra are shown in Fig 10 and 11, respectively.

3. Agriculture Scenario of Maharashtra

3.1 Introduction

The major challenge in today's scenario is to effectively feed the population from declining quality of natural resources. This will necessitate the development of technologies to increase crop productivity with out degrading natural resources. This in turn requires improved resource use efficiently. An attempt was made to create a digital database of production and productivity zones of major field crops of Maharashtra. About 13 field crops are grown in the state and the area under some of these crops exhibit wide inter-annual fluctuations for many reasons. Apart from the market demand, weather and socio-economic factors are some of the reasons causing such fluctuations. Districtwise database of area, production and productivity of 13 major field crops of Maharashtra has been collected and compiled from the Government websites *viz.,* www.apy.dacnet.nic.in and www.mahaagri.gov.in and various outputs were generated in both tabular and graphical forms. The following section deals with the major results and outcomes of the study.

3.2 Delineation of production zones of major field crops

The net sown area in the Maharashtra has been classified into different categories of production zones of major grown crops up to 2014-15. The criterion adopted for the categorization is the area under each crop and those districts contributing about 50% of the area in the state are termed as primary zone and districts contributing 35% of the net sown area under the crop are classified as secondary zones and the rest of the districts as tertiary zones. Parent 34 districts have been taken into account. Other areas (<1000 ha) in each district are put under the marginal category. The zones classified are shown in Table 9 and presented in Fig. 12-24. This type of categorization can help in planning the expansion of crops like pulses, oilseeds and implementing projects to expand areas under the crops currently grown or to introduce new crops or their cultivars into the new areas in suitable farming situations.

Table 9 : Production zones of major crops in Maharashtra (Area in "00" hectares)

Crops	Primary zone		Secondary zone		Tertiary zone		Others	
	Districts	Area	Districts	Area	Districts	Area	Districts	Area
Paddy	Bhandara, Gondia Chandrapur, Thane, Gadchiroli	7656	Satara, Nashik, Pune, Kolhapur, Nagpur, Ratnagiri, Raigad, Sindhudurg	5359	Jalgaon, Dhule, Solapur, Ahmednagar, Sangli, Nandurbar, Amravati, Buldhana, Wardha, Washim, Yavatmal, Aurangabad, Beed, Hingoli, Jalana, Latur, Nanded, Osmanabad, Parbhani	2297	Akola	Nil
***Kharif* Sorghum**	Solapur, Pune, Ahemadnagar	15560	Sangli, Parbhani, Osmanabad, Jalana, Aurangabad, Beed	10892	Jalgaon, Dhule, Nandurbar, Satara, Nashik, Kolhapur, Akola, Buldhana, Chandrapur, Gadchiroli, Nagpur, Wardha, Washim, Hingoli, Latur, Nanded	4668	Amravati, Bhandara Gondia, Yavatmal, Ratnagiri, Raigad, Thane, Sindhudurg	Nil
Pearl millet	Ahemadnagar, Nashik, Beed	6627	Jalgaon, Dhule, Pune, Aurangabad	4639	Solapur, Sangli, Nandurbar, Satara, Akola, Amravati, Buldhana, Washim, Yavatmal, Hingoli, Jalana, Latur, Nanded, Parbhani, Osmanabad	1988	Kolhapur, Thane, Bhandara, Gondia, Gadchiroli, Wardha, Raigad, Ratnagiri, Nagpur, Sindhudurg, Chandrapur	Nil
Ground nut	Sangli, Satara, Pune Kolhapur	1647	Dhule, Nandurbar, Nashik, Nagpur, Aurangabad, Beed, Latur, Nanded	1153	Jalgaon, Solapur, Ahmednagar, Amravati, Buldhana, Wardha, Yavatmal, Jalana, Osmanabad, Parbhani, Ratnagiri, Raigad, Thane, Sindhudurg	494	Akola, Bhandara, Chandrapur, Gadchiroli, Gondia, Washim, Hingoli	Nil
Soybean	Amravati, Buldhana, Nagpur, Washim, Yavatmal, Latur	17600	Akola, Chandrapur, Wardha, Hingoli, Nanded, Osmanabad, Parbhani	12320	Jalgaon, Dhule, Solapur, Ahmednagar, Sangli, Nandurbar, Satara, Nashik, Pune, Kolhapur, Bhandara, Beed, Gadchiroli, Aurangabad, Jalana	5280	Gondia, Ratnagiri, Raigad, Thane, Sindhudurg	Nil
Red gram	Amravati, Buldhana, Wardha, Yavatmal, Latur, Osmanabad, Parbhani	5796	Akola, Chandrapur, Nagpur, Washim, Aurangabad, Beed, Jalana, Nanded	4057	Jalgaon, Dhule, Solapur, Ahmednagar, Sangli, Nandurbar, Satara, Nashik, Pune, Kolhapur, Bhandara, Gadchiroli, Gondia, Hingoli, Ratnagiri, Raigad, Thane	1739	Sindhudurg	Nil

Black gram	Jalgaon, Buldhana, Latur, Nanded, Osmanabad	2819	Dhule, Solapur, Nandurbar, Nashik, Akola, Washim, Beed, Hingoli, Jalana, Parbhani	1973	Ahmednagar, Sangli, Satara, Pune, Kolhapur, Amravati, Bhandara, Chandrapur, Gadchiroli, Gondia, Nagpur, Wardha, Yavatmal, Aurangabad, Ratnagiri, Raigad, Thane, Sindhudurg	846		Nil
Green gram	Akola, Amravati, Buldhana, Washim	3501	Jalgaon, Dhule, Yavatmal, Jalana, Latur, Nanded, Osmanabad, Parbhani	2450	Solapur, Ahmednagar, Sangli, Nandurbar, Satara, Nashik, Pune, Kolhapur, Bhandara, Chandrapur, Gadchiroli, Gondia, Nagpur, Wardha, Aurangabad, Beed, Hingoli, Ratnagiri, Raigad, Thane, Sindhudurg	1050		Nil
Cotton	Buldhana, Jalna, Jalgaon, Yavatmal, Aurangabad	15977	Wardha, Dhule, Amravati, Beed, Akola, Parbhani, Nanded	11184	Solapur, Hingoli, Osmanabad, Ahmednagar, Sangli, Nandurbar, Satara, Nashik, Pune, Kolhapur, Gondia, Chandrapur, Latur, Gadchiroli, Nagpur, Washim	4793	Bhandara, Gondia, Ratnagiri, Raigad, Thane, Sindhudurg	Nil
Wheat	Solapur, Beed Ahemadnagar, Nashik, Pune, Amravati, Nagpur, Buldhana	6170	Jalgaon, Dhule, Satara, Akola, Chandrapur, Latur, Yavatmal, Parbhani, Aurangabad, Hingoli	4319	Sangli, Nandurbar, Kolhapur, Bhandara, Gadchiroli, Gondia, Wardha, Washim, Jalana, Nanded, Osmanabad	1851	Ratnagiri, Raigad, Thane, Sindhudurg	Nil
Rabi sorghum	Jalgaon, Sangli, Yavatmal, Latur, Nanded	6353	Satara, Akola, Amravati, Buldhana, Hingoli, Osmanabad, Parbhani	4447	Dhule, Solapur, Ahmednagar, Nandurbar, Nashik, Pune, Kolhapur, Chandrapur, Nagpur, Wardha, Washim, Aurangabad, Beed, Jalana	1906	Bhandara, Gadchiroli, Gondia, Ratnagiri, Raigad, Thane, Sindhudurg	
Safflower	Hingoli, Latur, Osmanabad, Parbhani	1394	Solapur, Ahemadnagar, Pune, Aurangabad, Beed, Jalana	976	Sangli, Nandurbar, Satara, Nashik, Akola, Amravati, Buldhana, Washim, Yavatmal, Nanded	418	Jalgaon, Dhule, Thane, Kolhapur, Bhandara, Chandrapur, Gondia, Gadchiroli, Nagpur, Wardha, Ratnagiri, Raigad, Sindhudurg	Nil
Sugarcane	Solapur, Ahemadnagar, Pune Kolhapur	5148	Sangli, Satara, Nashik, Aurangabad, Beed, Hingoli, Jalana, Latur, Nanded, Osmanabad, Parbhani	3603	Jalgaon, Dhule, Nandurbar, Amravati, Bhandara, Buldhana, Chandrapur, Gadchiroli, Gondia, Nagpur, Wardha, Washim, Yavatmal	1544	Akola, Ratnagiri, Raigad, Thane, Sindhudurg	Nil

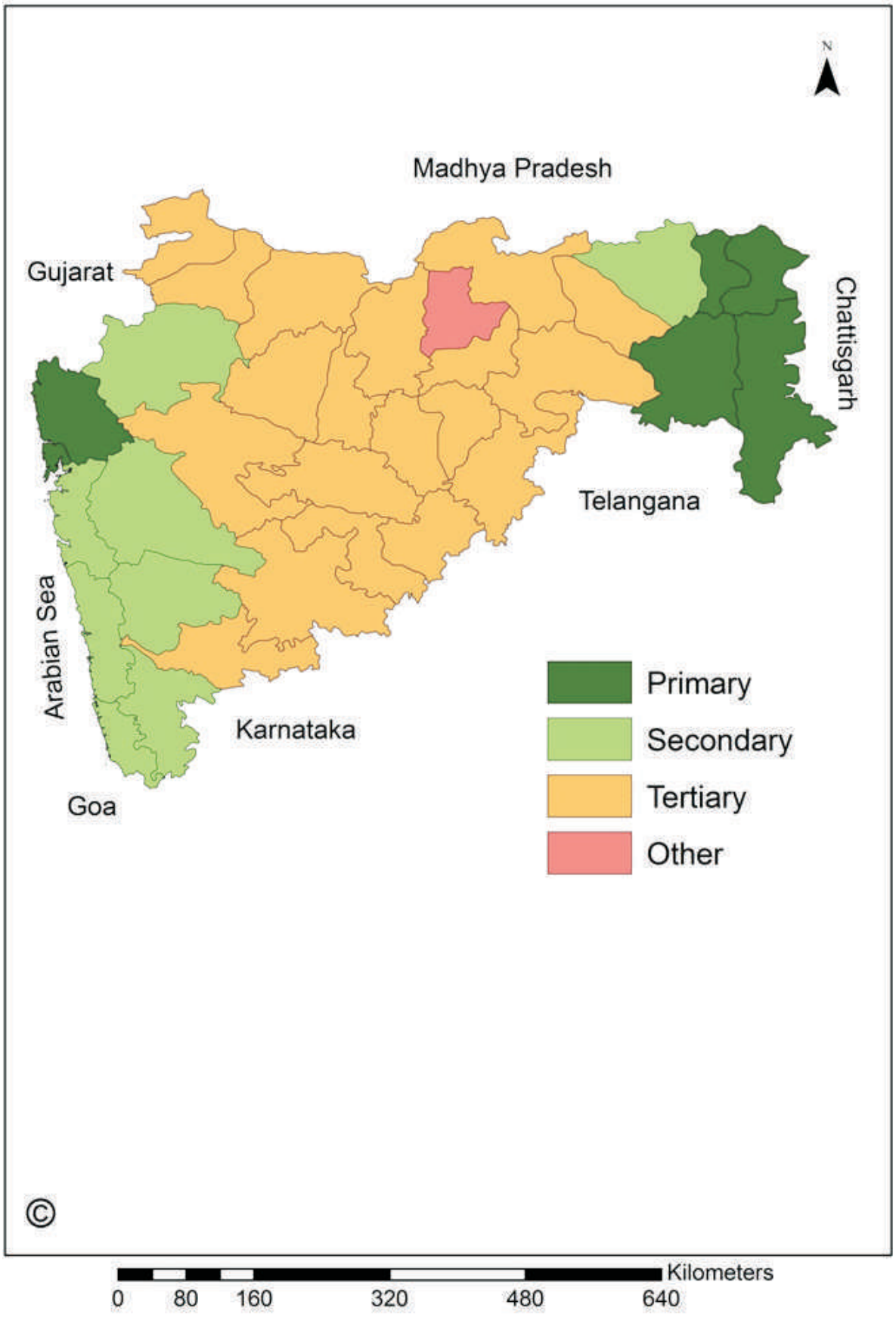


Fig. 12 : Delineation of different production zones of paddy

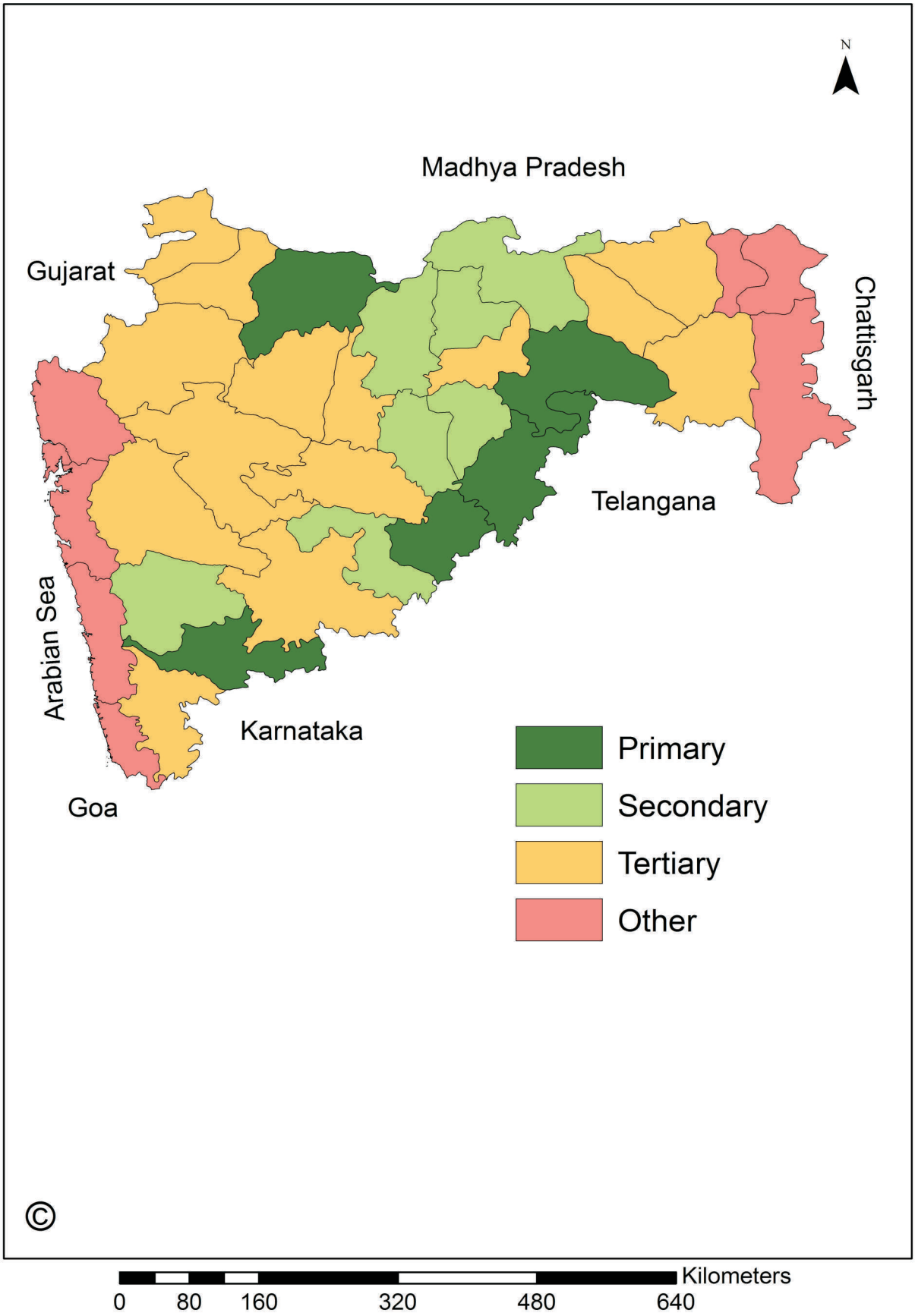


Fig. 13 : Delineation of different production zones of kharif sorghum

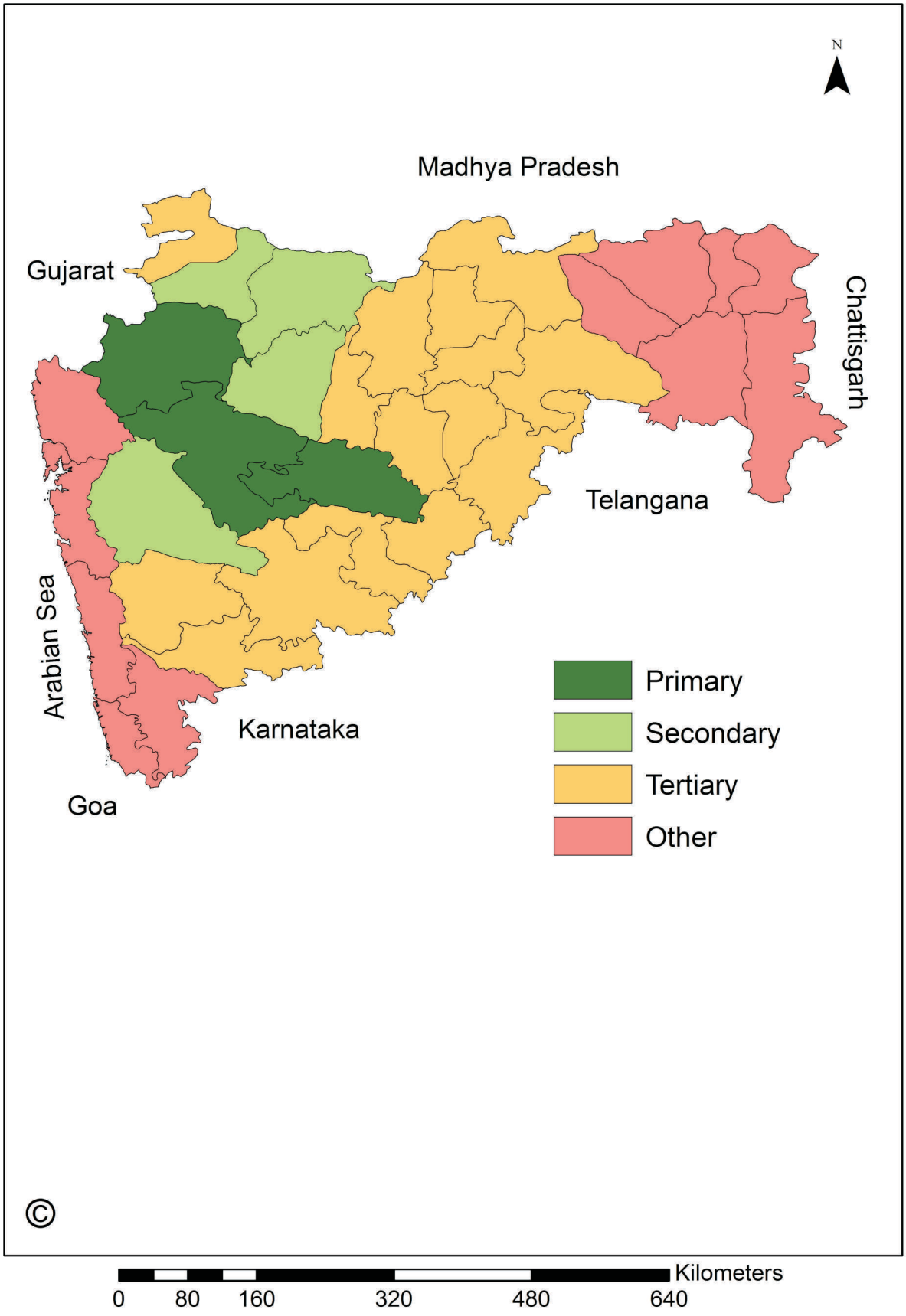


Fig. 14 : Delineation of different production zones of Pearl millet

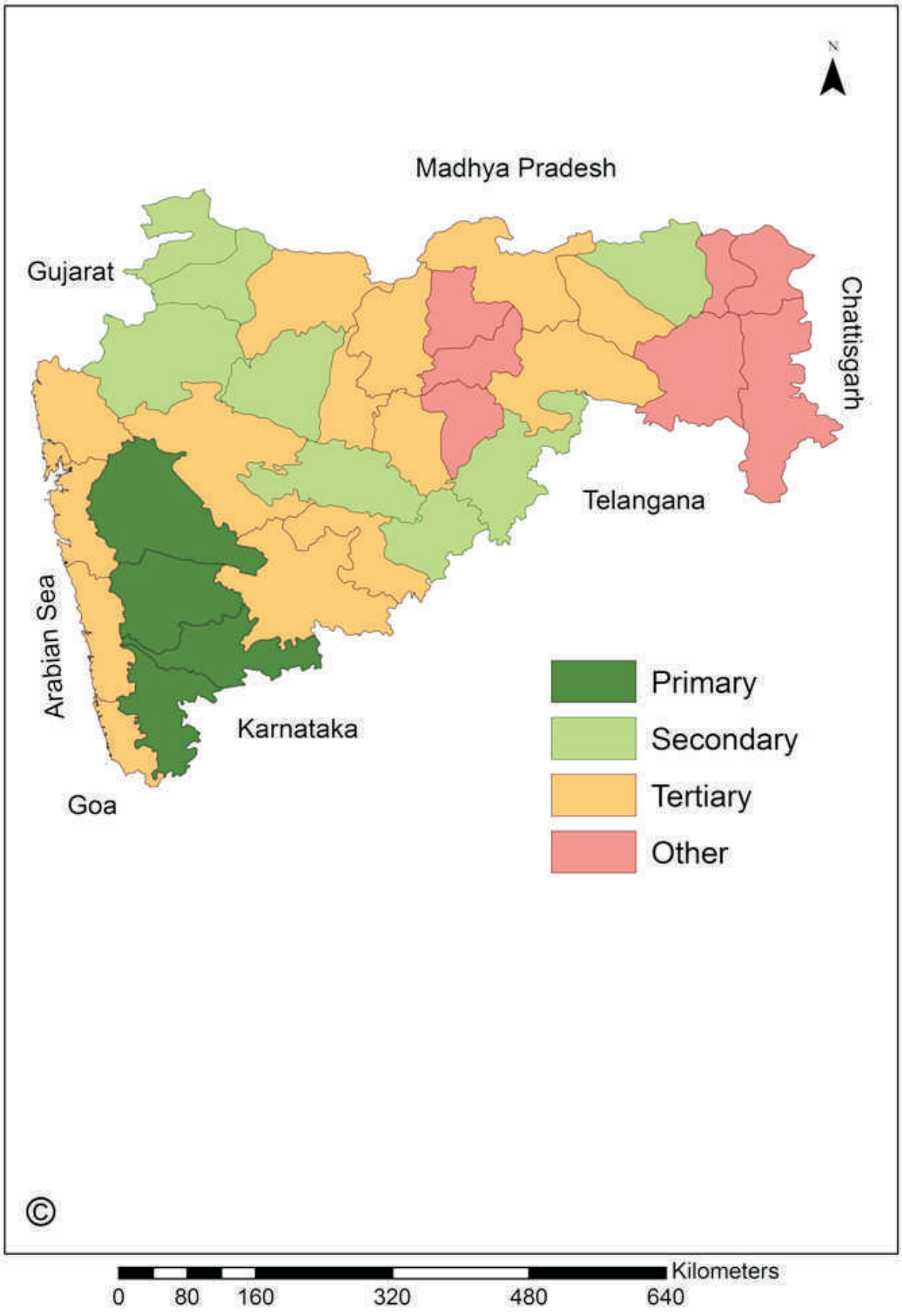


Fig. 15 : Delineation of different production zones of Groundnut

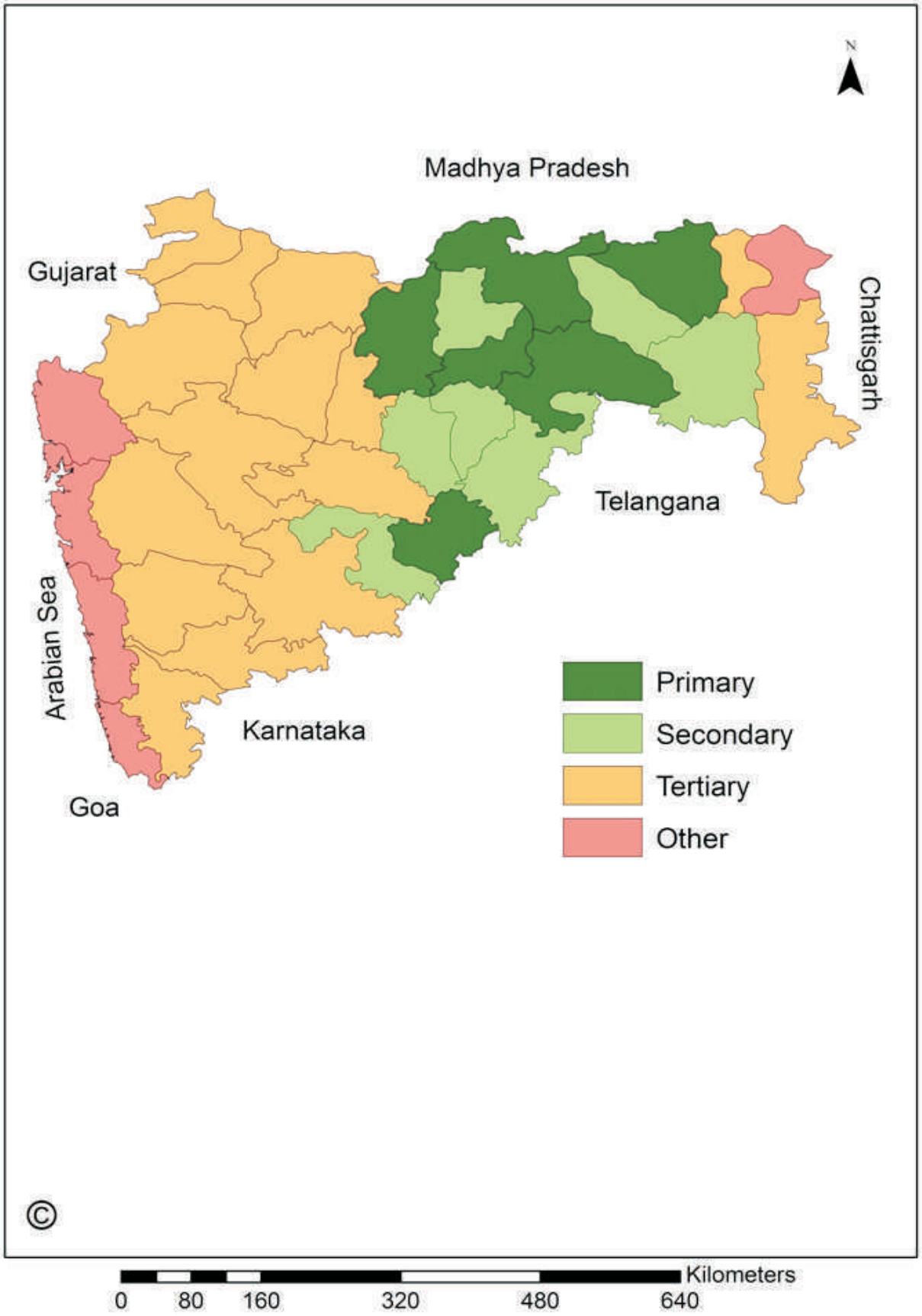


Fig. 16 : Delineation of different production zones of Soybean

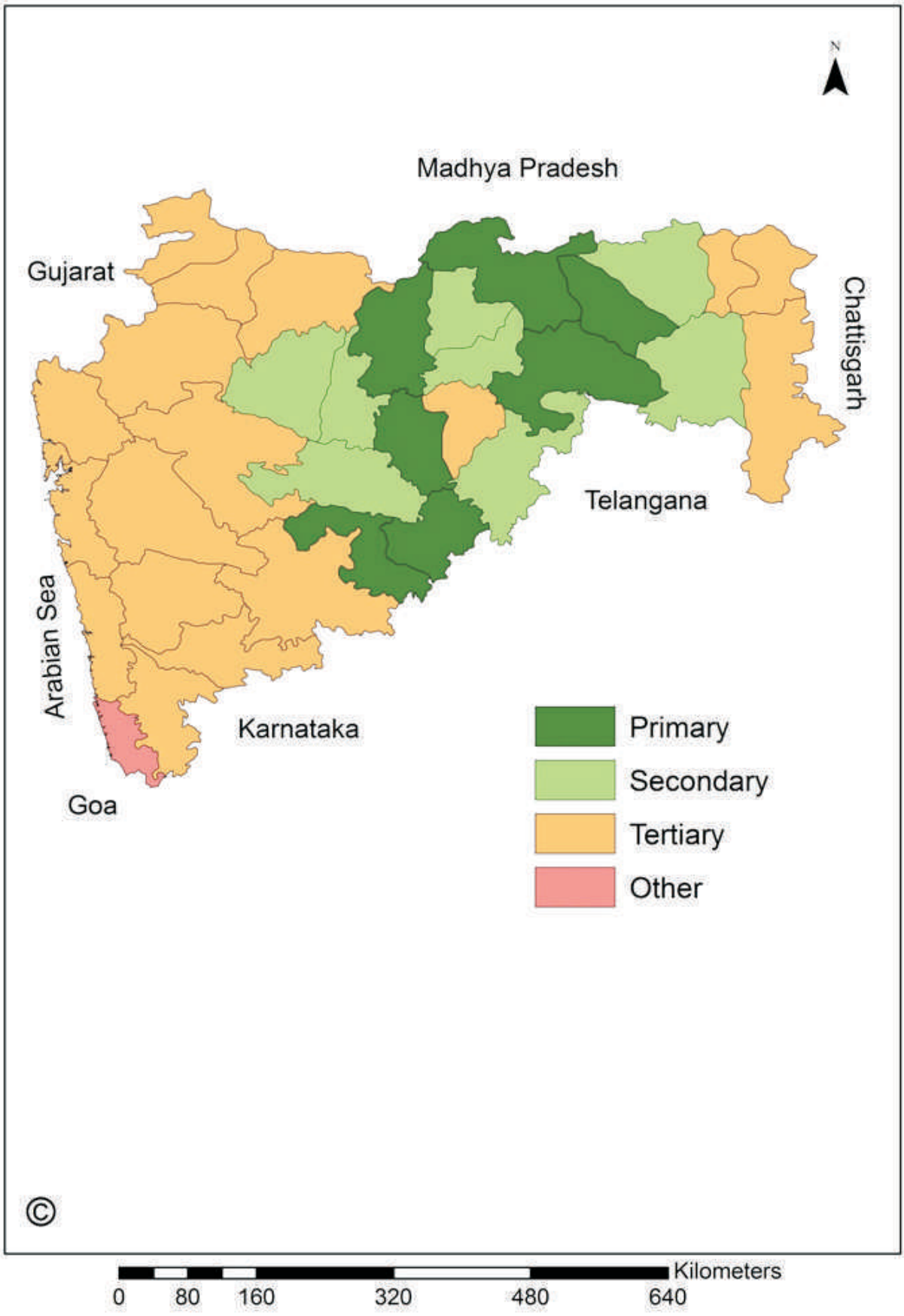


Fig. 17 : Delineation of different production zones of Red gram

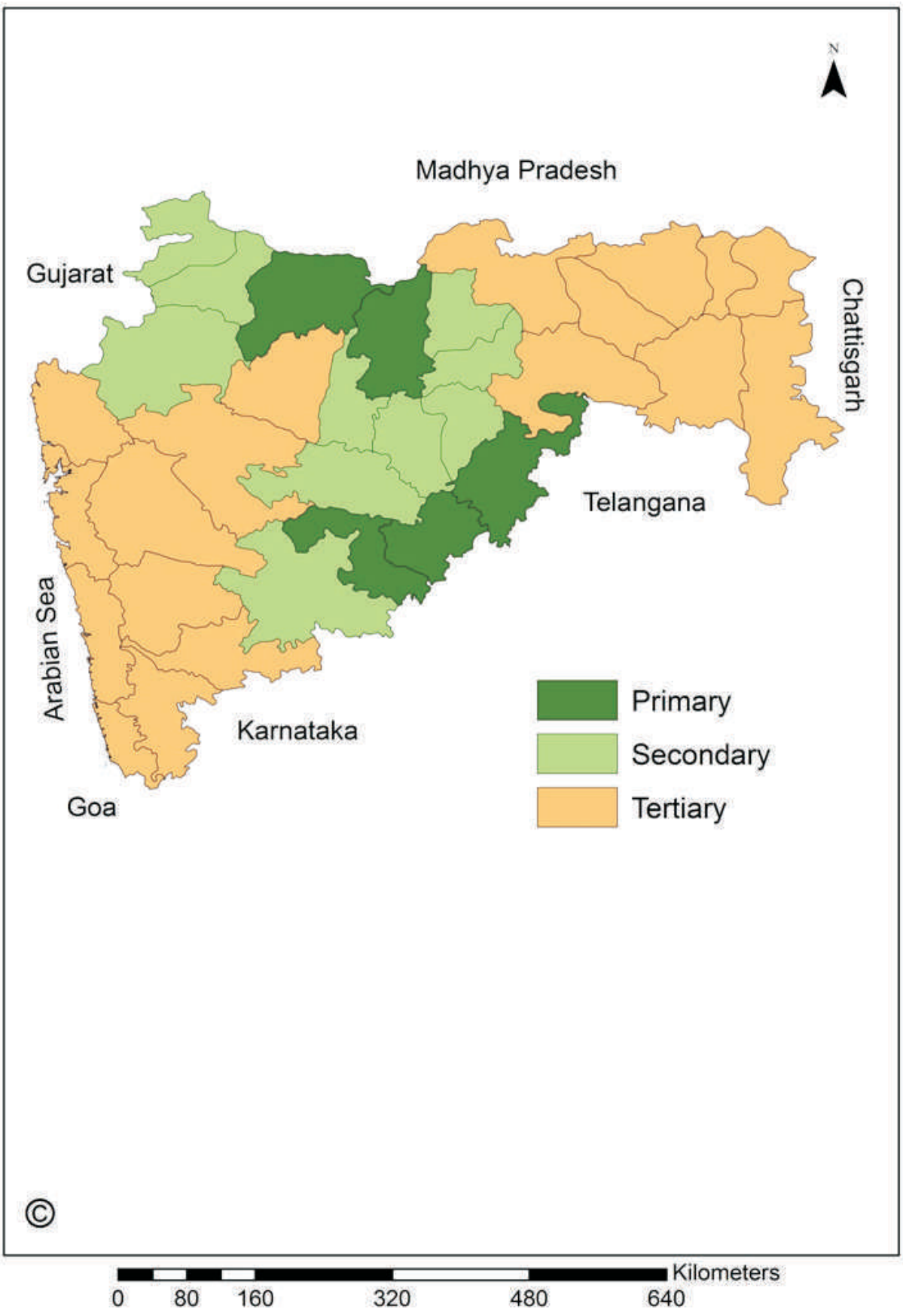


Fig. 18 : Delineation of different production zones of Black gram

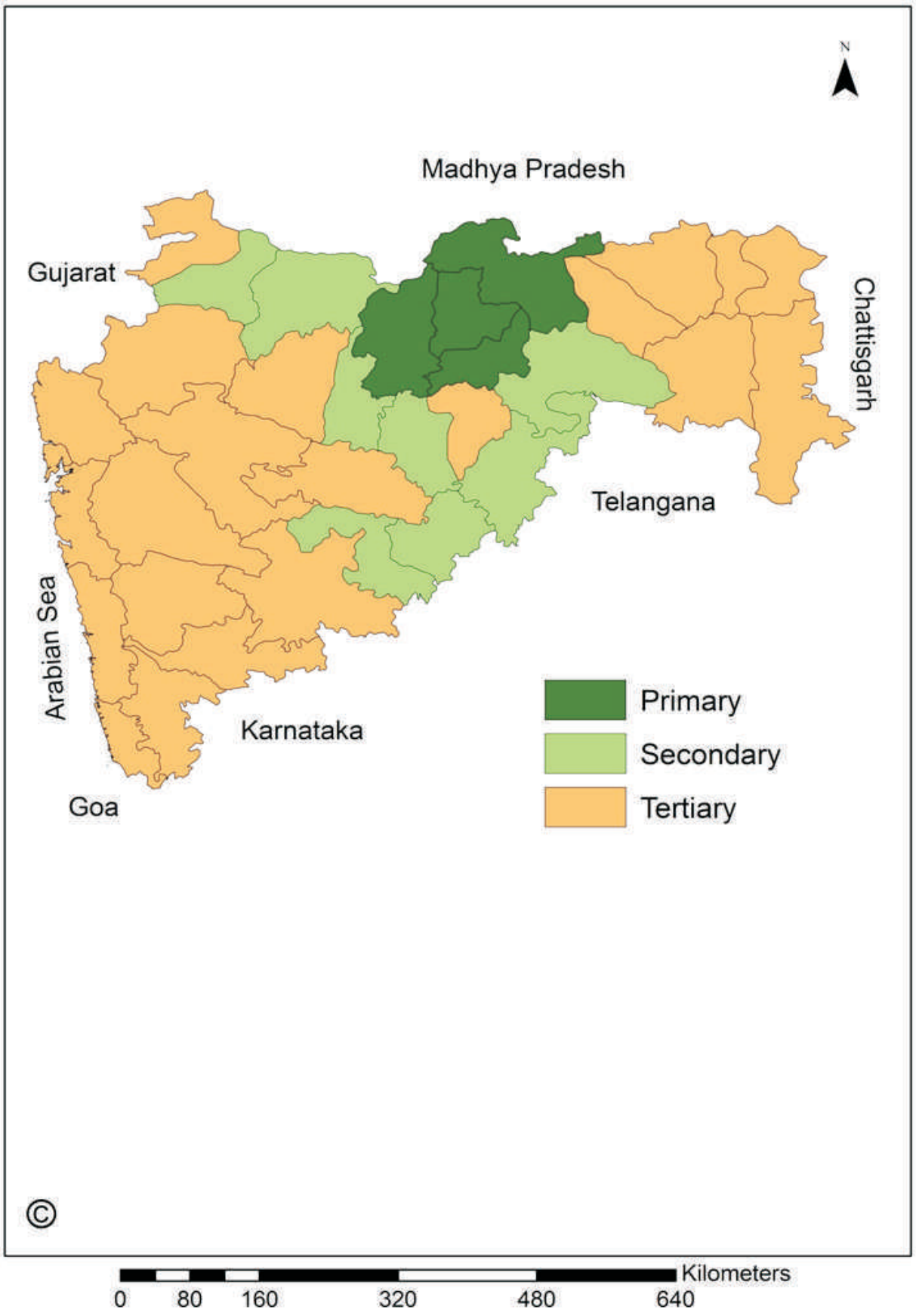


Fig. 19 : Delineation of different production zones of Green gram

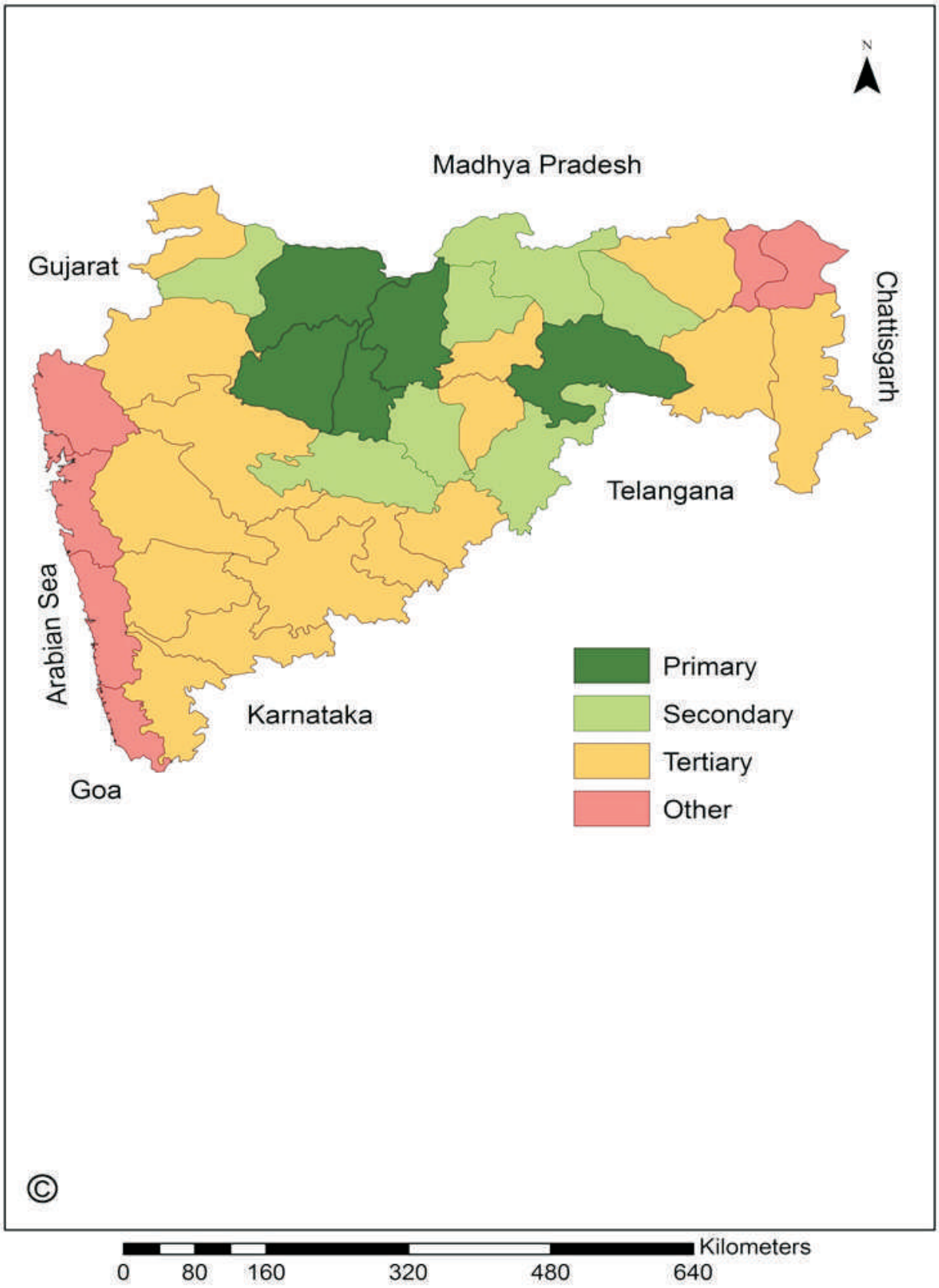


Fig. 20 : Delineation of different production zones of Cotton

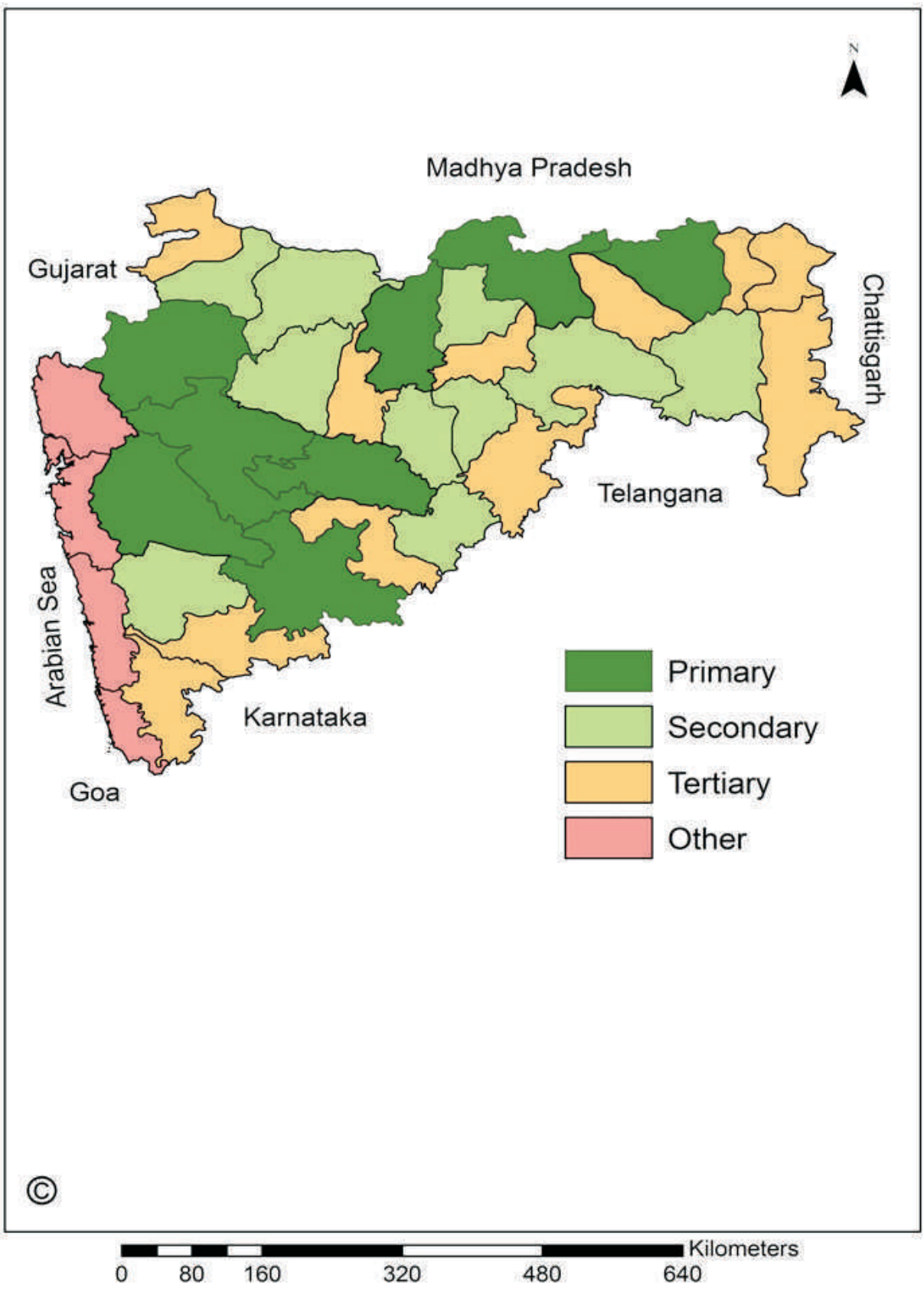


Fig. 21 : Delineation of different production zones of Wheat

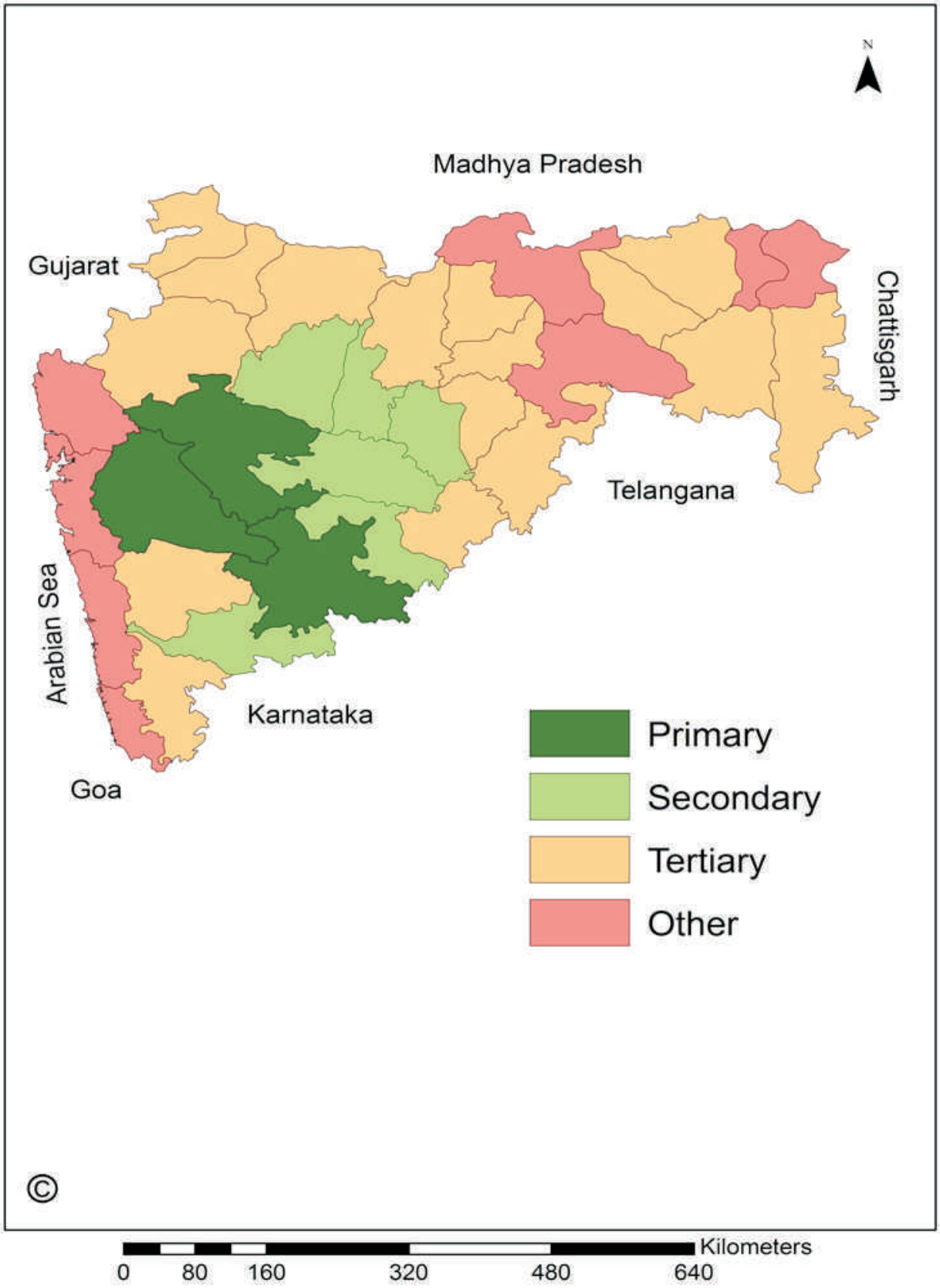


Fig. 22 : Delineation of different production zones of Rabi Sorghum

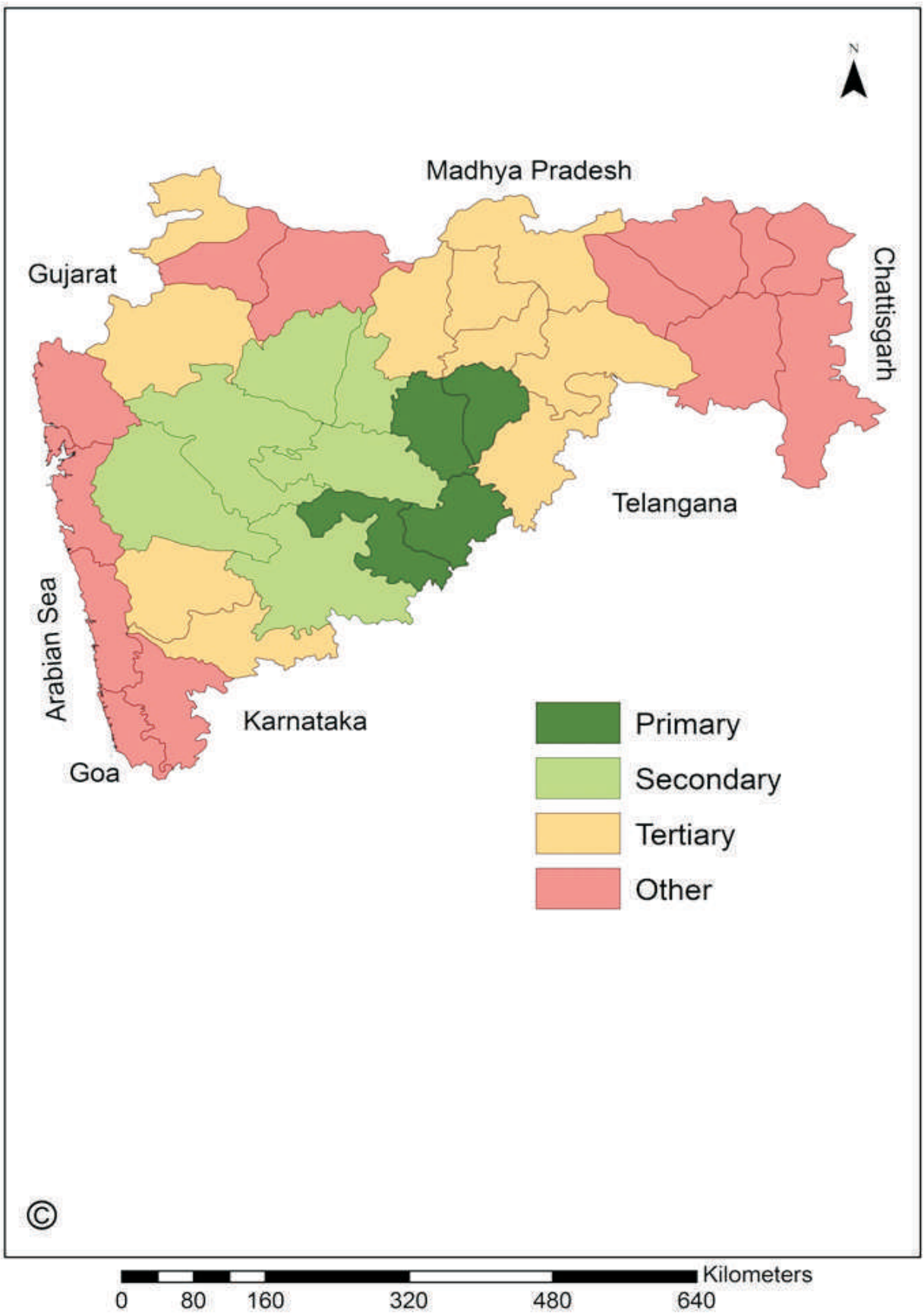


Fig. 23 : Delineation of different production zones of Safflower

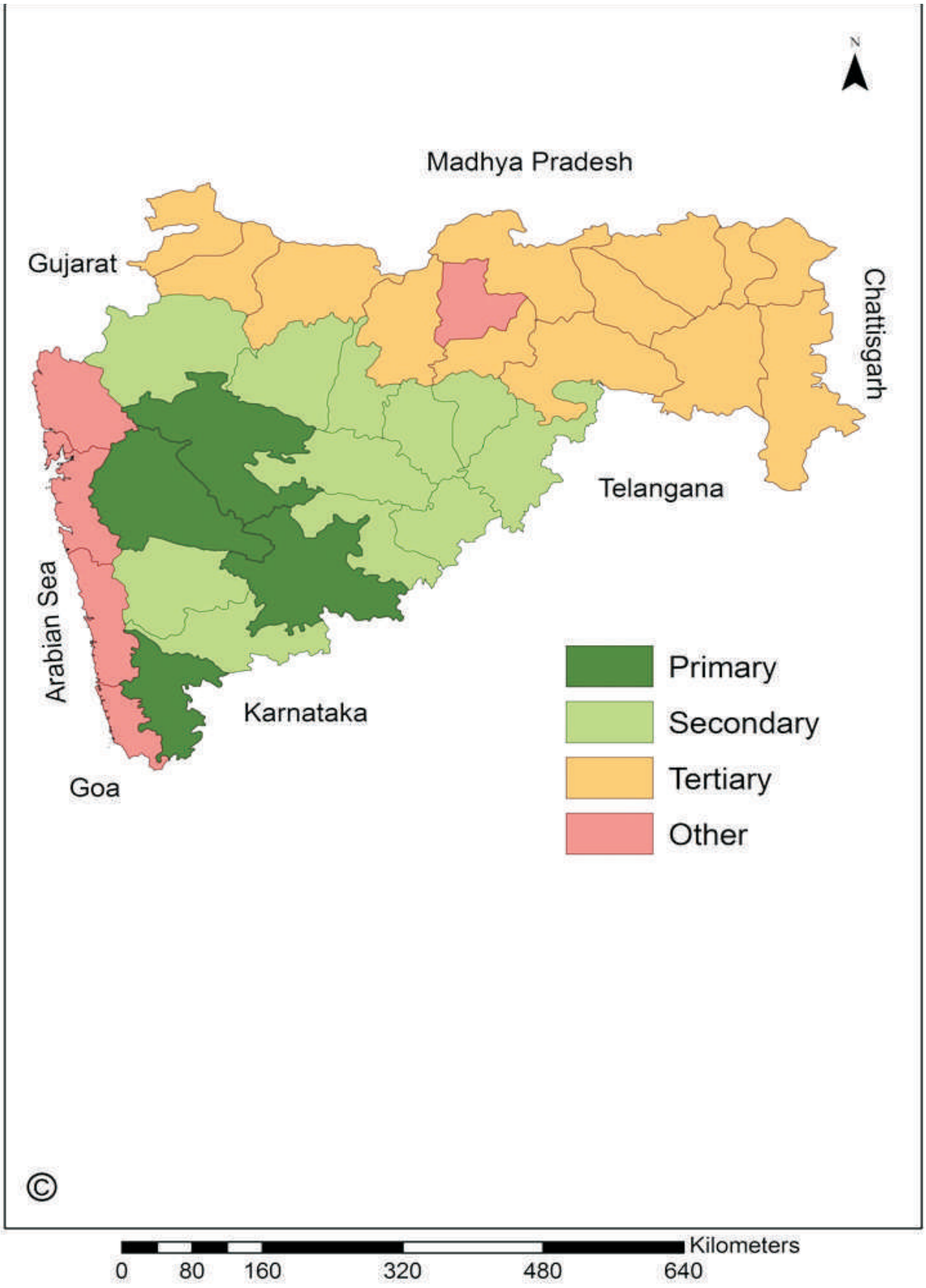


Fig. 24 : Delineation of different production zones of Sugarcane

3.3 Area, production and productivity trends of major crops

On region basis, area, production and productivity trends are shown in Fig. 25-37 for the major field crops. Rice and maize showed increasing trend in area, production and productivity while in case of pearl millet decreasing trend is noticed in area and production while productivity is showing increasing trend. Groundnut area and production is decreasing and productivity is increasing. This will give an insight to the planners to go further for micro-level analysis regarding sustainability and profitability of a particular crop and cropping system is a given area

3.3.1 Cereals

Paddy, sorghum and pearl millet are the principal cereal crops of Maharashtra. The area under paddy is about 15 lakh ha and there is a marginal increase in area over the years (Fig. 25). The year to year fluctuations in area are mostly due to the drought and scanty rainfall. Drought conditions from 2010 onwards led to drastic reduction of the area. Paddy production has consistently increased @ 2.21 lakh tons per year. The paddy productivity has risen from 362 kg ha^{-1} to 1538 kg ha^{-1} during the 55 year period from 1960 to 2015. Sorghum is the second largest cereal crop due to its commercial value (as cattle feed). It is grown both in *kharif* and *rabi* season. The grown area under *kharif* sorghum has fallen from 31.1 lakh ha to 6.2 lakh ha in last 55 years (Fig. 26). Productivity level of *kharif* sorghum has increased from 305 kg ha^{-1} in 1972 to 1425 kg ha^{-1} in 2011. However, in case of *rabi* sorghum, the area has decreased from 37.8 lakh ha in the 1971 to 15.1 lakh ha in 2013 (Fig. 35). The steep increase in the productivity levels of the crop has to some extend has compensated the sharp decline in the area.

Pearl millet is another important cereal crop grown mostly in semi-arid region of Maharashtra. Area under pearl millet during 1960-2015 witnessed significant decrease. Maharashtra showed slight ups and downs in production but as such an overall increase in a production was observed from 1992 to 2000 and again there was decline in the production 2001 onwards (Fig. 27). Maharashtra showed steady increase in the pearl millet productivity during the period of 1960 to 2015. Maharashtra showed slight variation in the wheat area but as such an overall increase in an area under wheat was observed from 1960 to 2015 (Fig 34). The area under wheat improved during 2006 to 2010 and decreased during the 2011-12 and 2013-14. Production of wheat showed increasing trend from 1960 to 2015. The yield of *rabi* sorghum improved steadily from 1960 to 2015, but the productivity trend was constant through the period.

3.3.2 Oilseeds

Groundnut, soybean and safflower are the major oilseeds crop of Maharashtra. Soybean occupies the largest area in the state. Area under soybean increased from 0.7 lakh ha in 1987 to 36.4 lakh ha in 2014. Its production and productivity have shown a sharp increase over the years (Fig. 29). Major shift that occurred in the past decades in favour of soybean crop was due to its early duration, suitability for double cropping, distinct yield advantage, higher price and better market support. The area under soybean has also substituted more of *kharif* sorghum and some

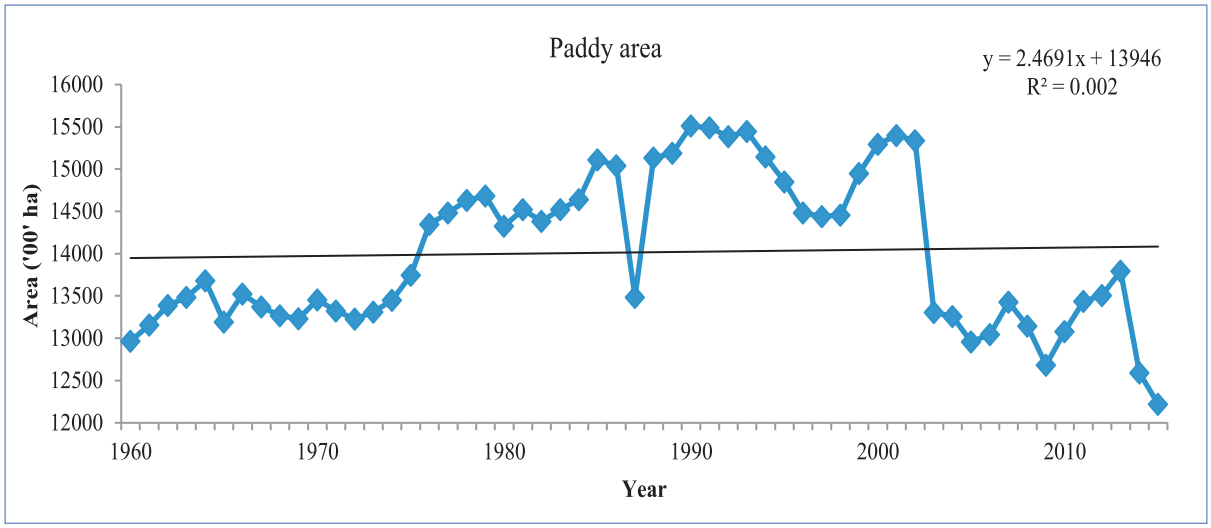
cotton acreage. Groundnut is grown on 2.41 lakh ha. The area under this crop was at its peak during 1960-1966 when it averaged at 6.2 lakh ha (Fig. 28). The production trend of this crop have shown steep decline over the years due to variation in the spread of rainfall. Similarly, area under safflower is also showing a sharp decline, with a marginal decrease in production. This may be due to the introduction of improved cultivars and better production technology (Fig. 36).

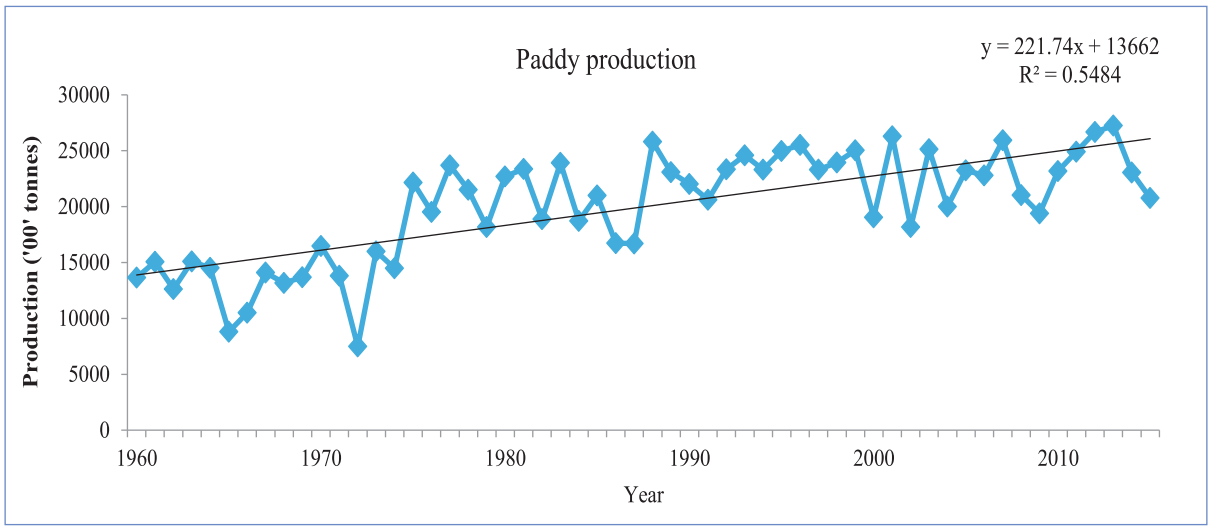
3.3.3 Pulses

The major pulse crops of the state are red gram, black gram and green gram. Area under red gram has picked up in recent years since it is a good dry land pulse crop. Introduction of high yielding cultivars has raised productivity of the crop from 321 kg ha^{-1} during 1972 to 810 kg ha^{-1} in 2007 (Fig. 30). Red gram area has risen from 5.30 lakh ha during the period 1960-61 to 13.01 lakh ha in 2010. This rise is partly due to introduction of pulses improvement program and partly to market forces (Fig. 30). In other years, the inter-annual variability is largely weather driven. Area, production and productivity of black gram varied over the years. Though there was a marginal rise in all the three parameters during the second part of the 1990s, 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. 31). Area and production under green gram showed a marginal ascent in recent years but productivity levels have been sustained due to the use of improved package of practices (Fig. 32).

3.3.4 Commercial crops

Cotton is the principal commercial crop of the state. It is cultivated on more than 41 lakh ha. Though productivity figures show large variability there has been a constant increase in area and production chiefly due to the introduction of Bt cotton. 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. 33). Apart from the spatial and temporal distribution of rainfall, insect pest damage is another important parameter that affects cotton productivity in Maharashtra. In tropical zone, Maharashtra is the major sugarcane growing state. The sugar industry is instrumental in generating sizable employment in the rural areas directly and through its ancillary units. It is estimated that about 50 million farmers and their dependents are engaged in the cultivation of sugarcane and about 0.5 million skilled and unskilled workers are engaged in sugar factories and its allied industries. The sugar industry in India has been a focal point for socio-economic development in the rural areas by mobilizing rural resources, generating employment and enhancing farm income. Some of the sugar factories have also diversified into by-products based industries and have put up distilleries, organic chemical plants, paper, ice board factories and cogeneration plants. A steep increase in sugarcane area and production has come through with a concurrent increase in the area over the years (Fig. 37). Very small inter-annual variation in the productivity of the crop may be attributed primarily to the fact that large area under sugarcane crop is irrigated.





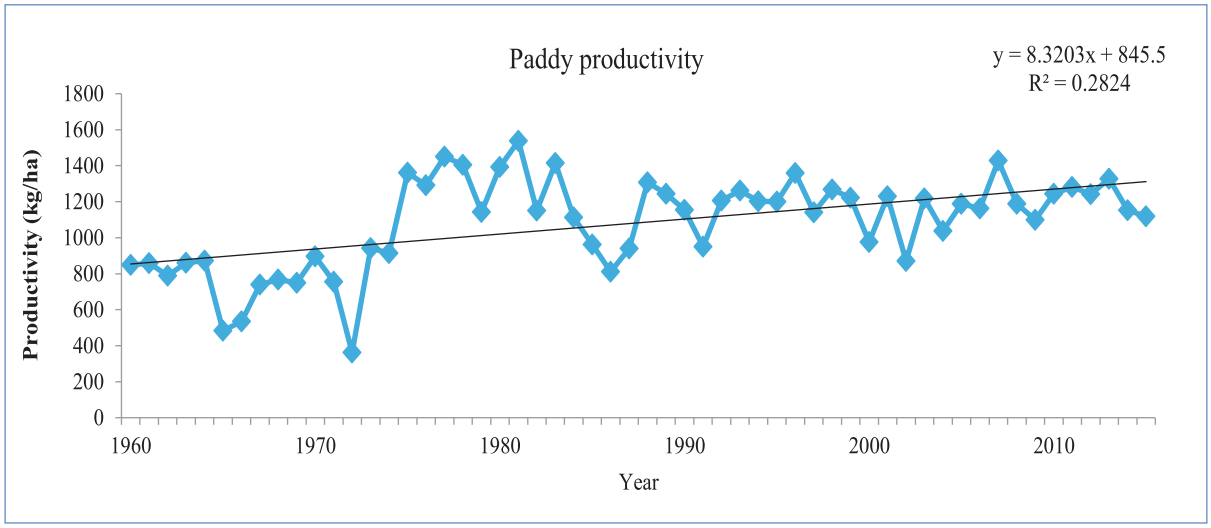


Fig. 25 : Trends in area, production and productivity of paddy (1960-2015)

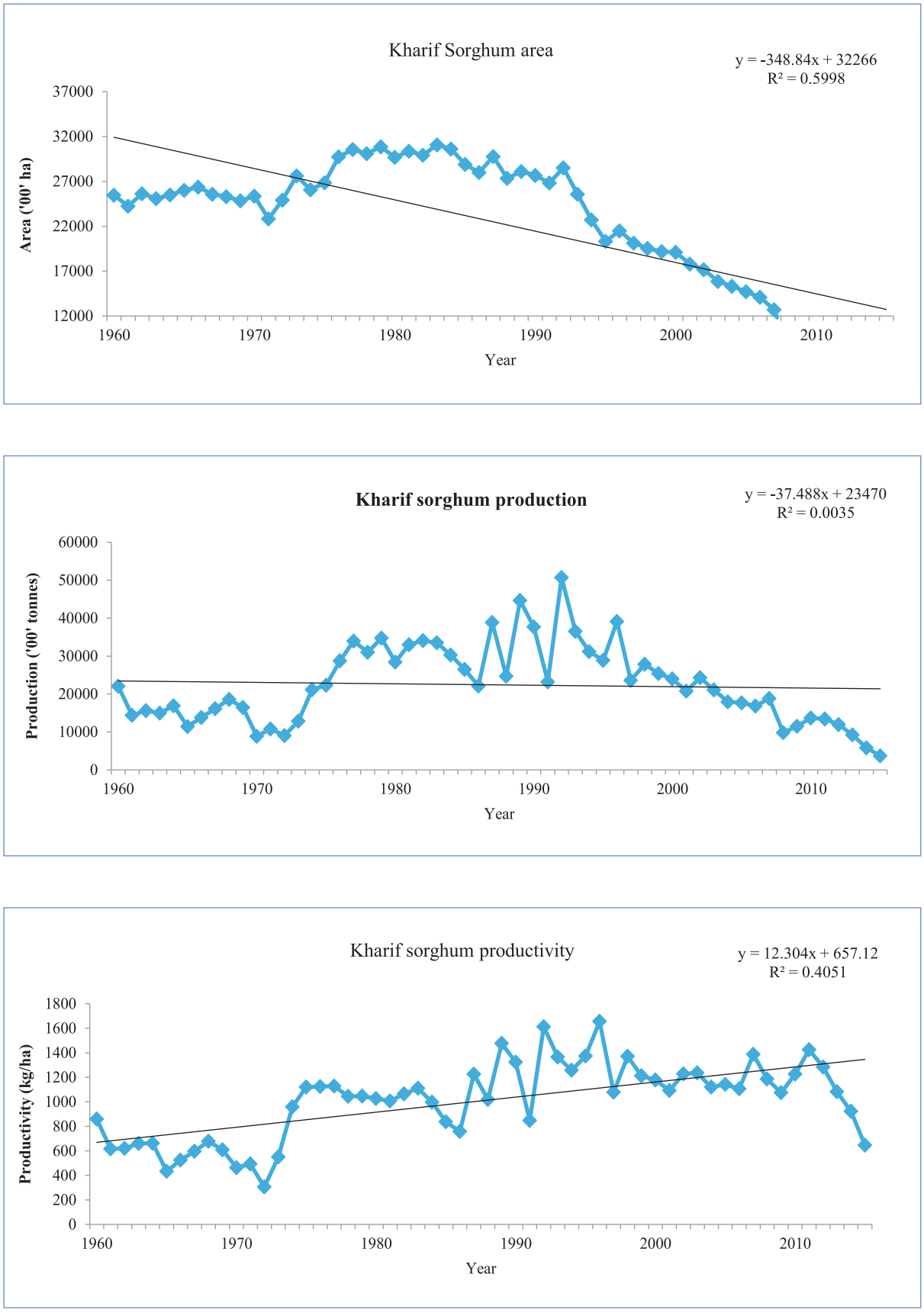


Fig. 26 : Trends in area, production and productivity of *Kharif* Sorghum (1960-2015)

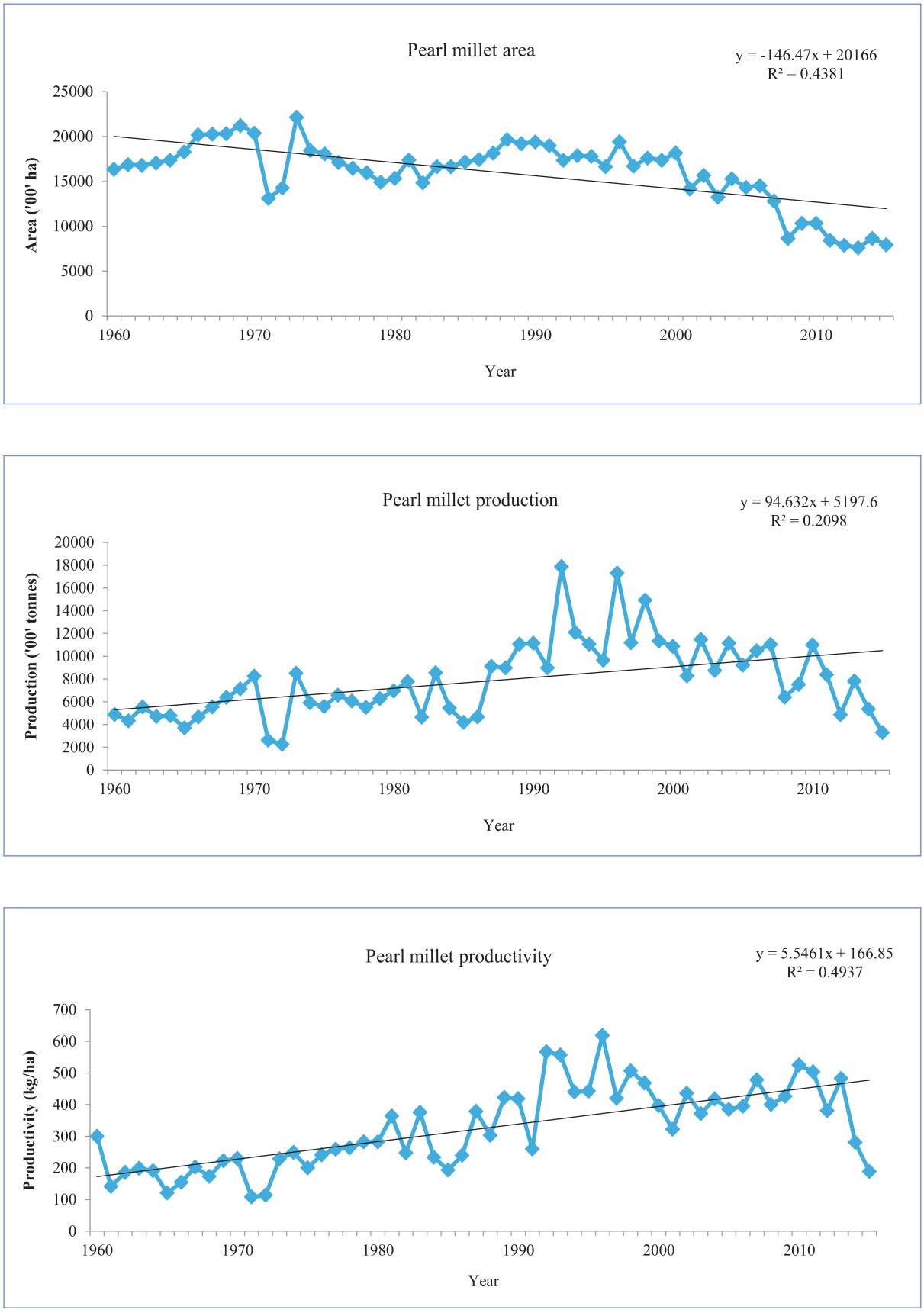
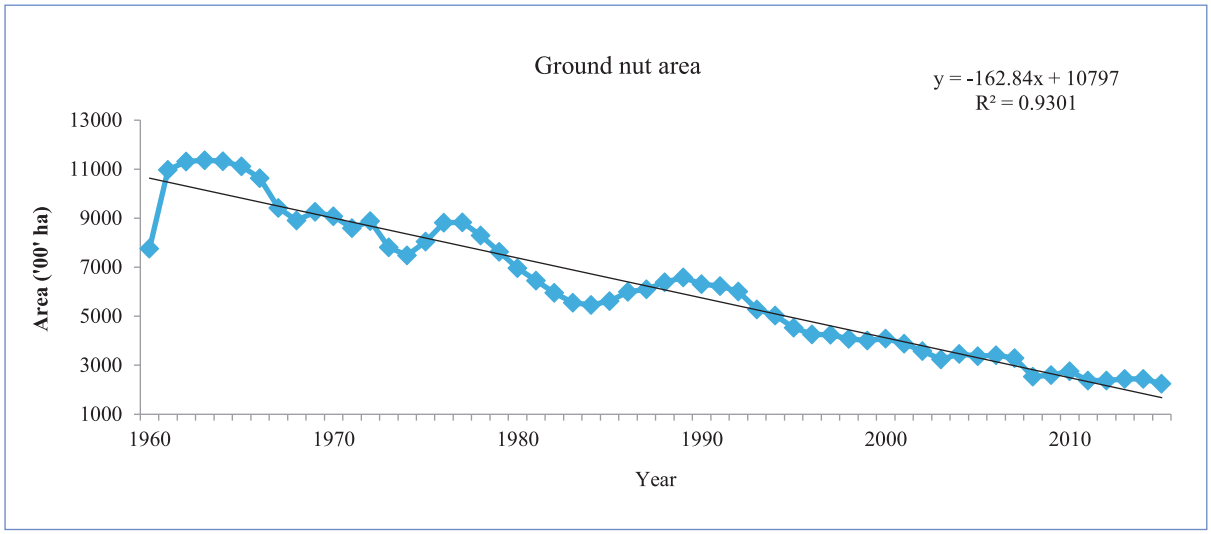
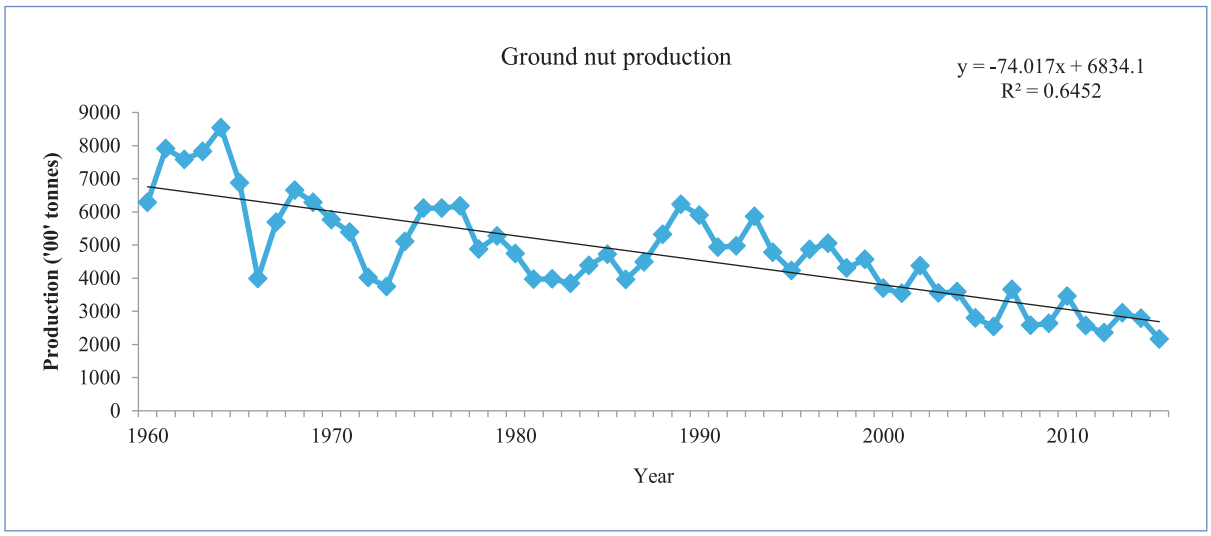


Fig. 27 : Trends in area, production and productivity of pearl millet (1960-2015)





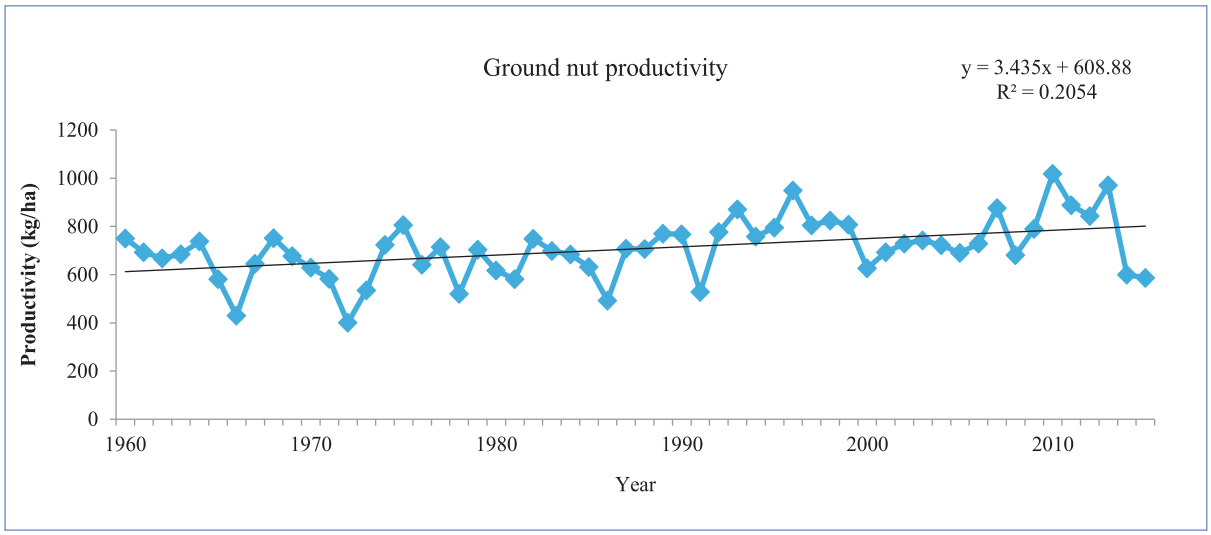
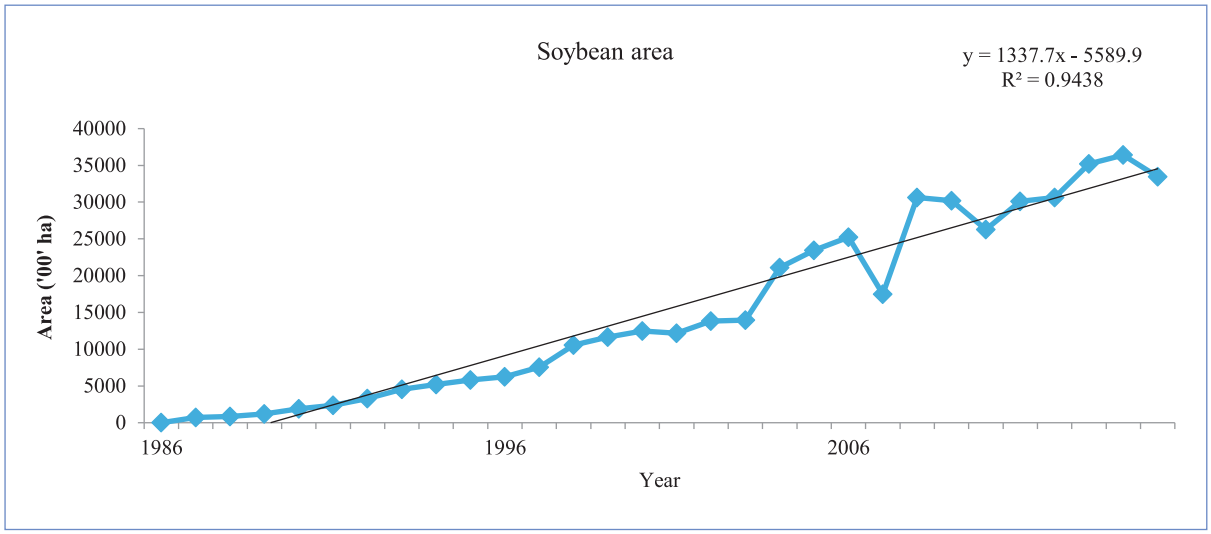
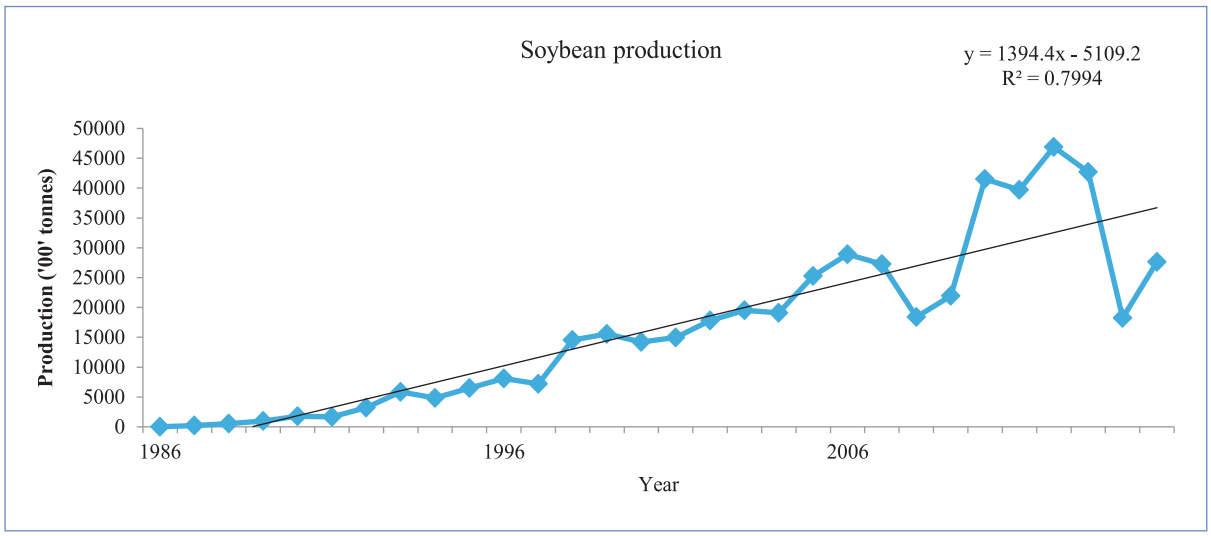


Fig. 28 : Trends in area, production and productivity of Ground nut (1960-2015)





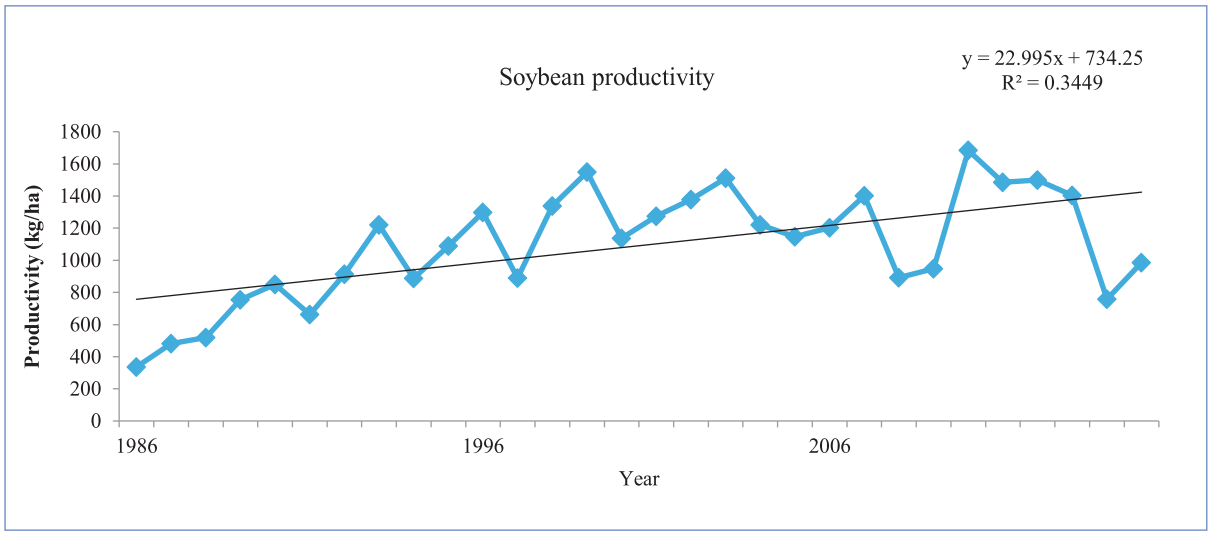
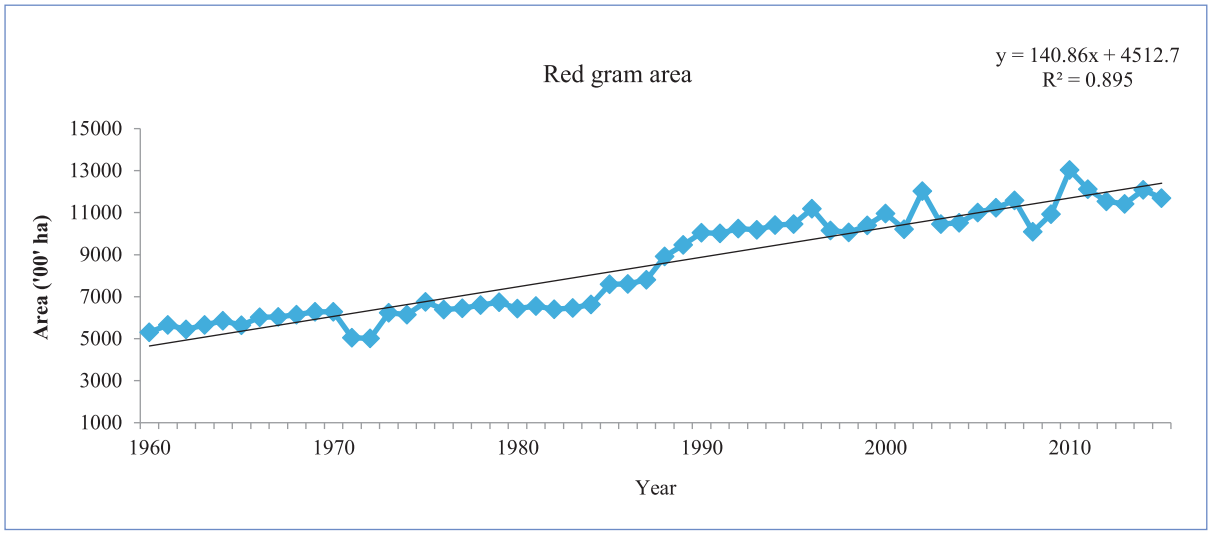
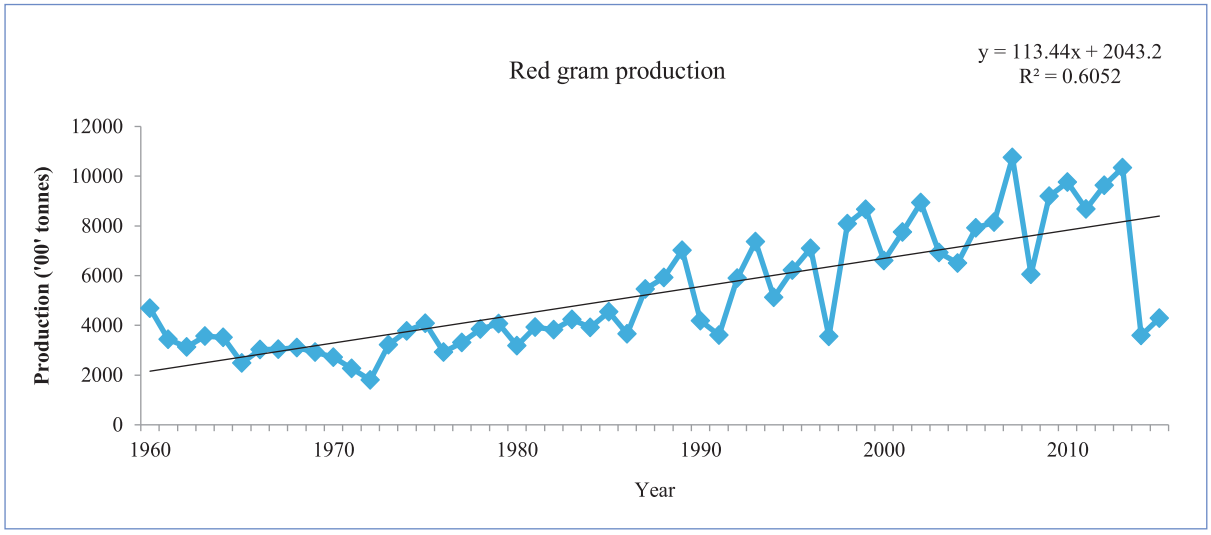


Fig. 29 : Trends in area, production and productivity of Soybean (1986-2015)





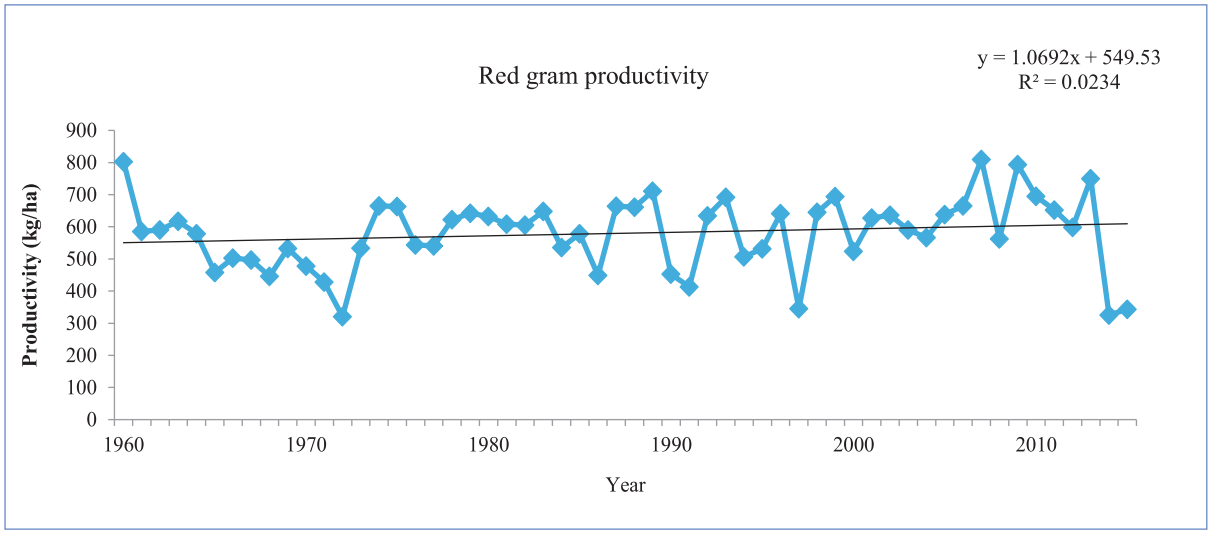
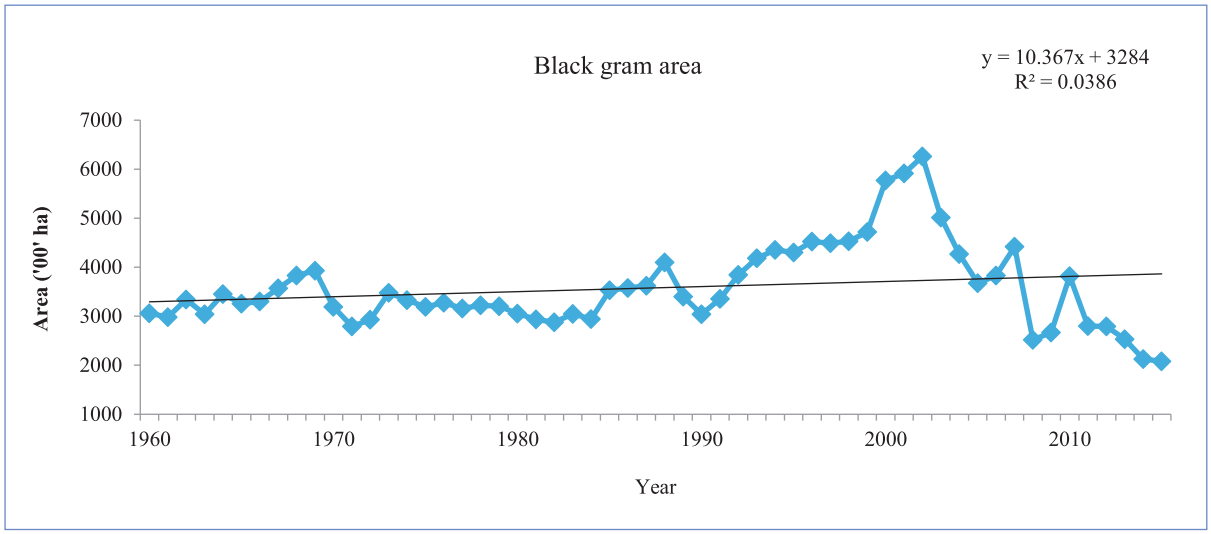
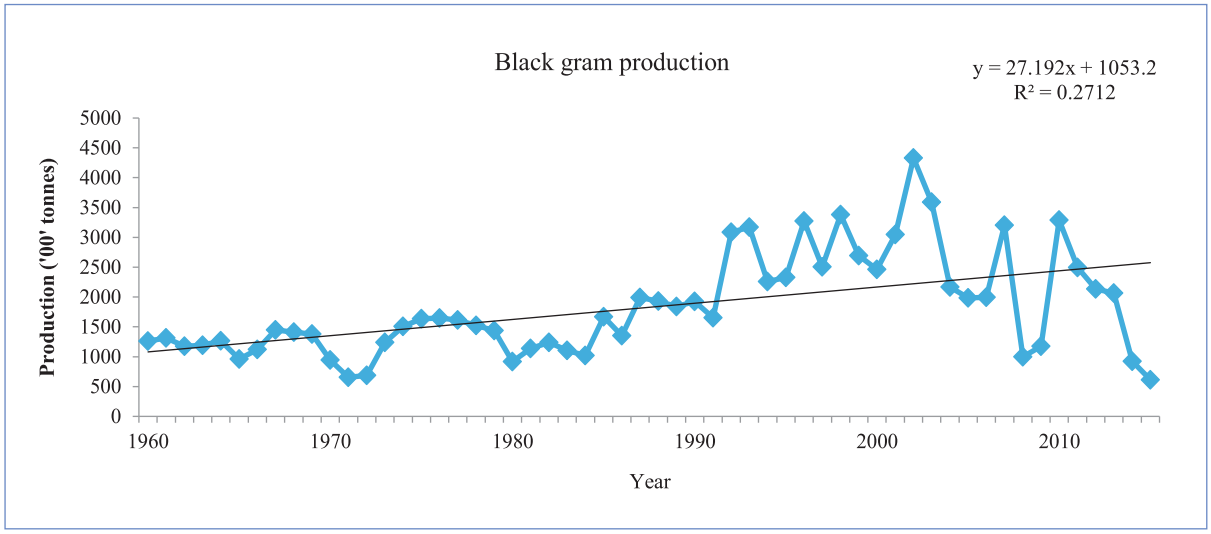


Fig. 30 : Trends in area, production and productivity of Red gram (1960-2015)





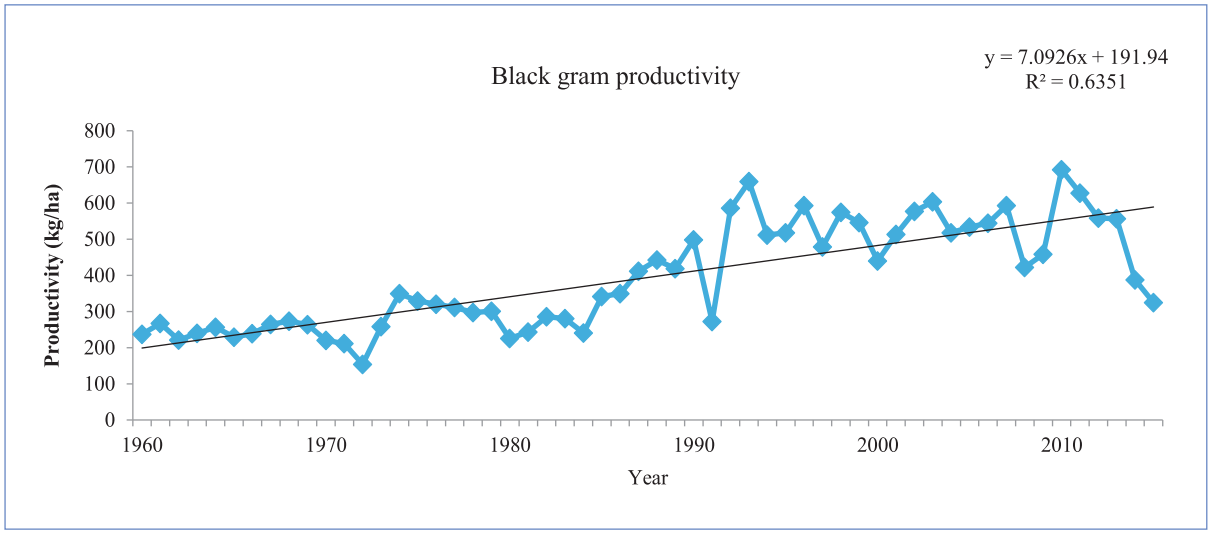


Fig. 31 : Trends in area, production and productivity of Black Gram (1960-2015)

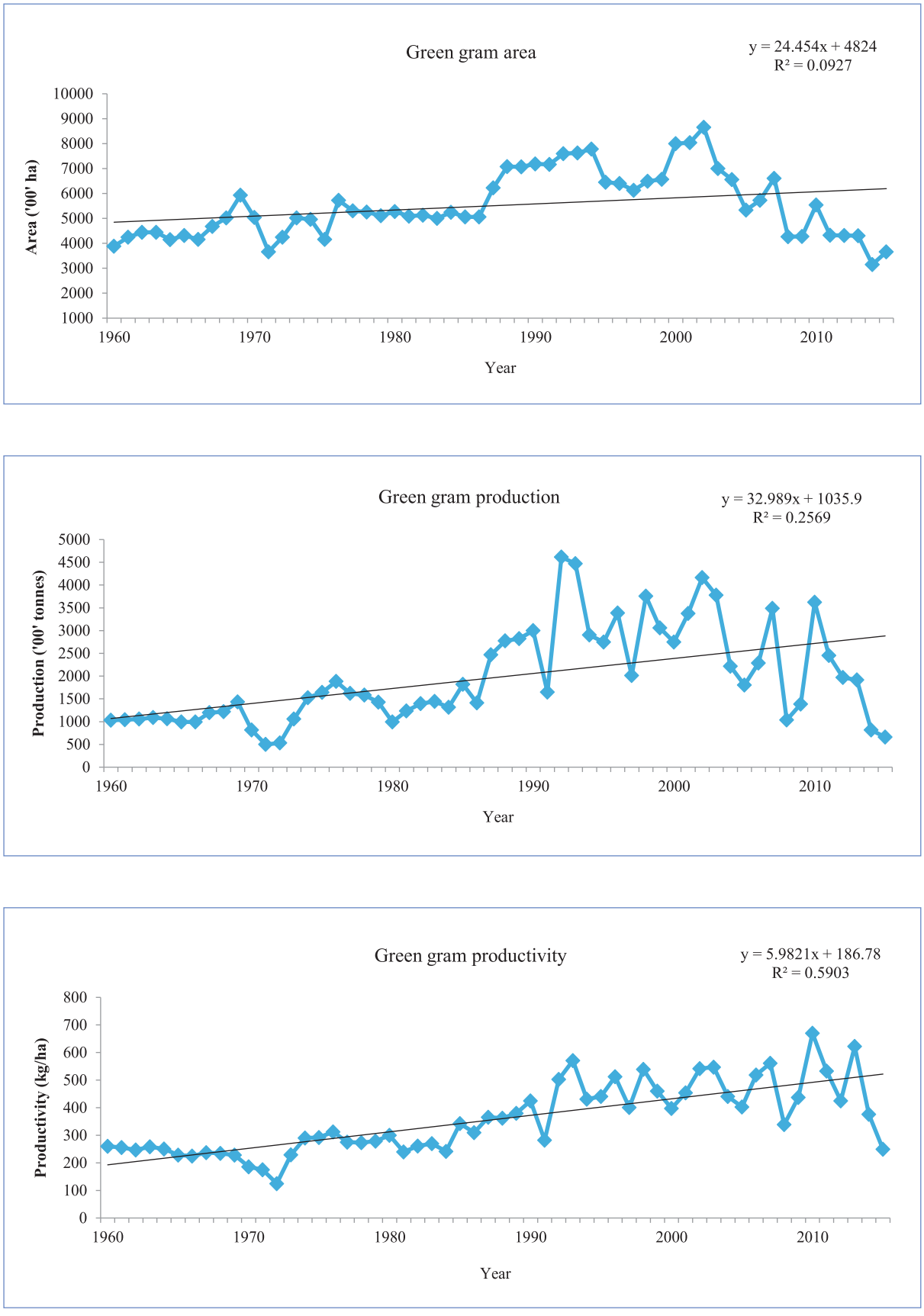


Fig. 32 : Trends in area, production and productivity of Green gram (1960-2015)

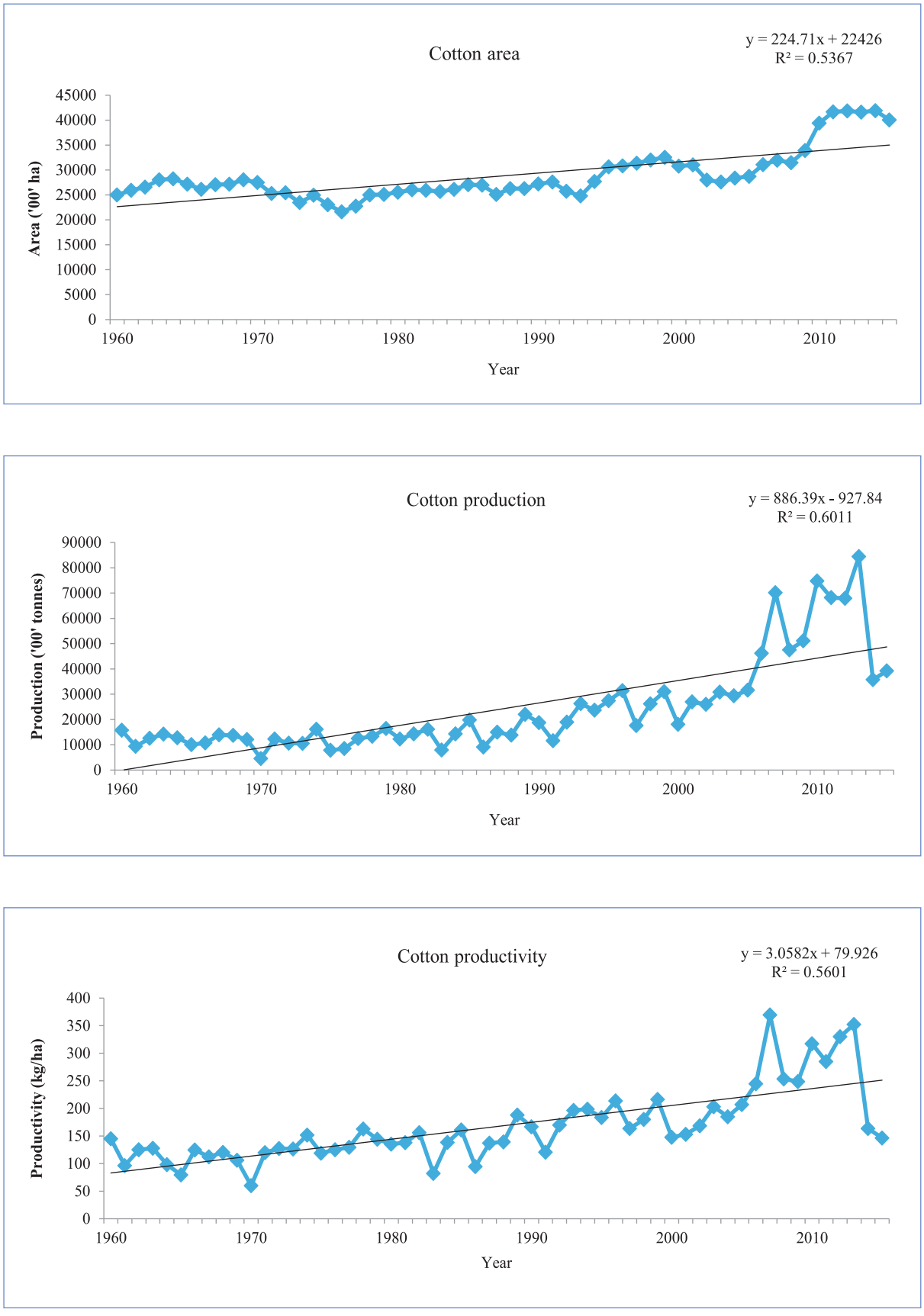


Fig. 33 : Trends in area, production and productivity of Cotton (1960-2015)

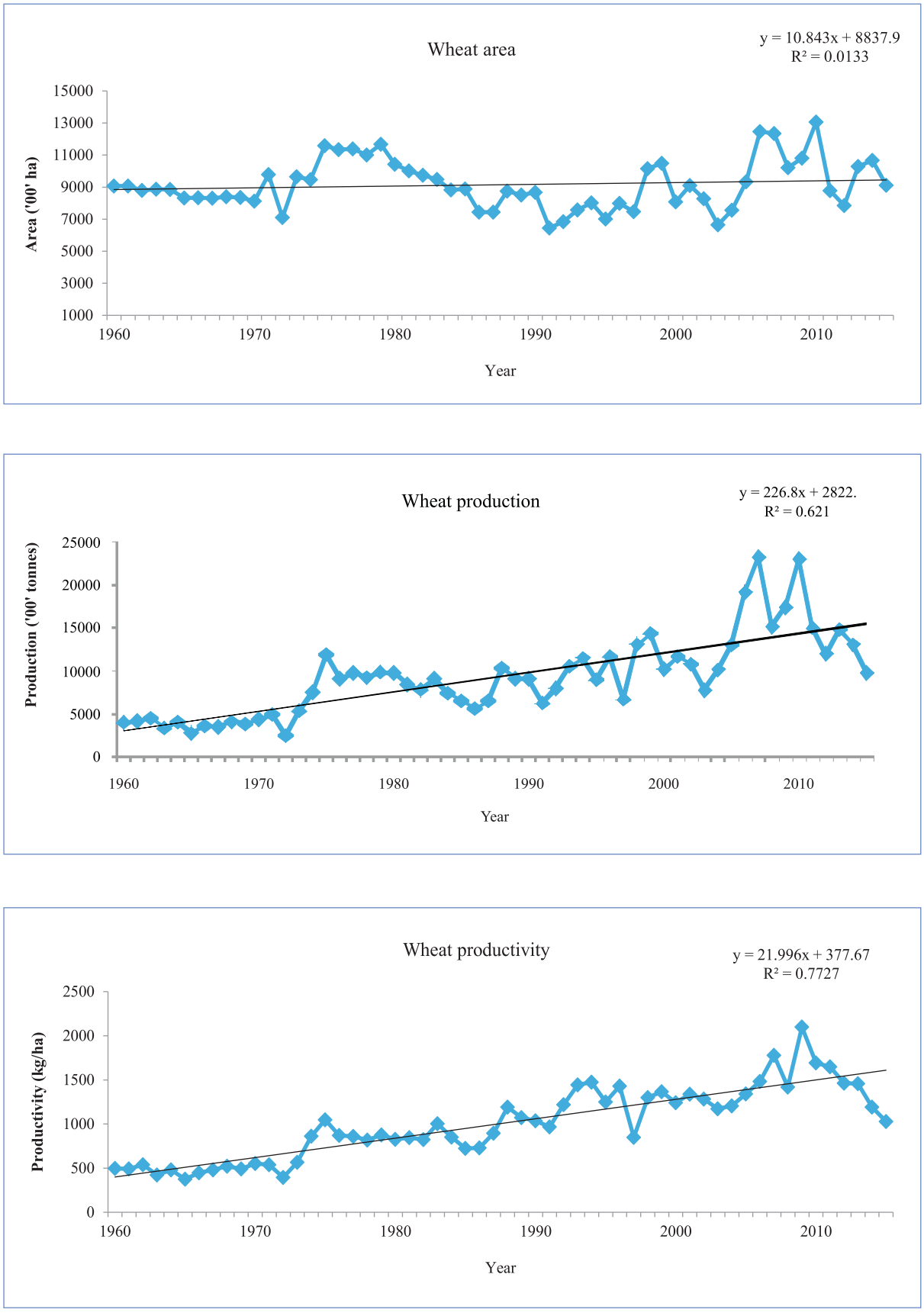


Fig. 34 : Trends in area, production and productivity of Wheat (1960-2015)

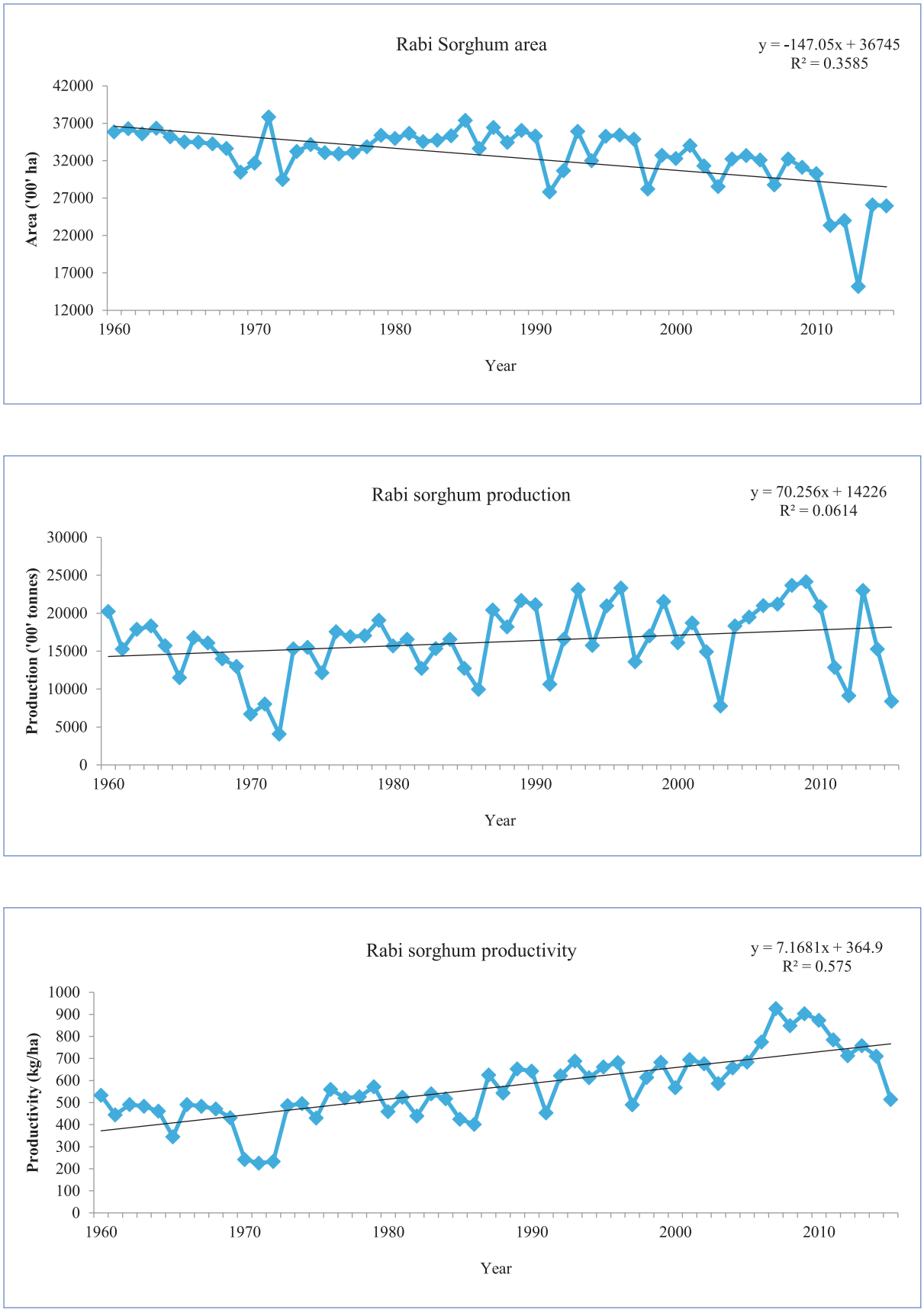
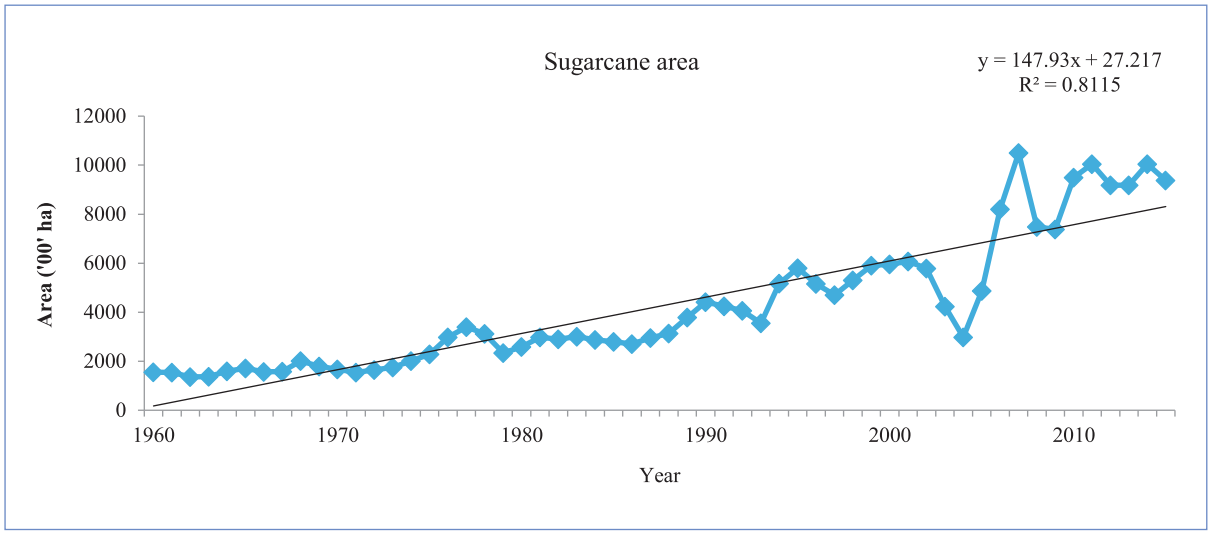
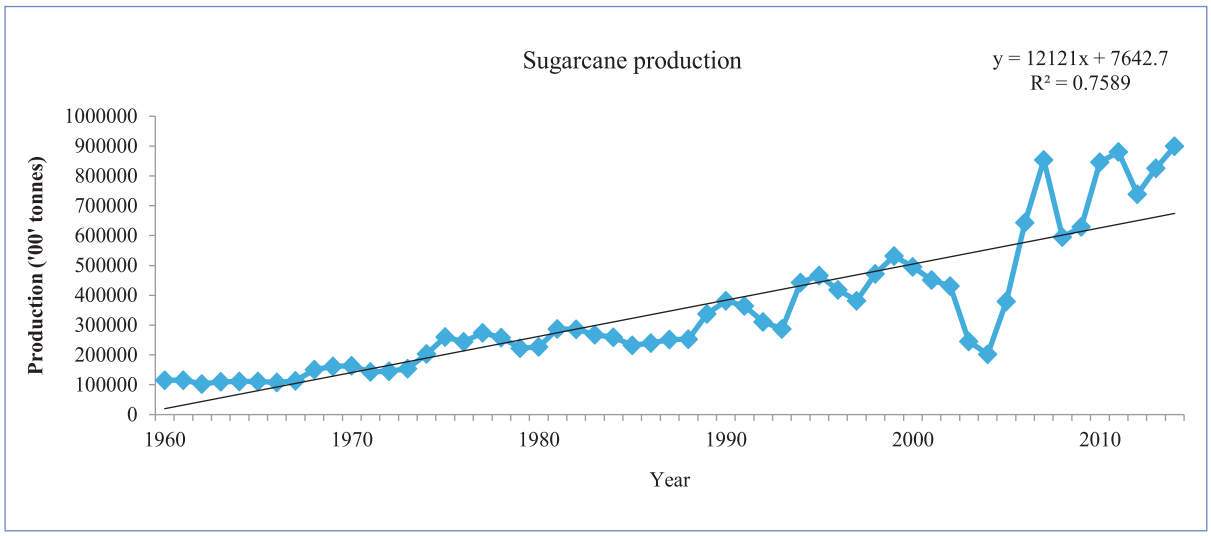


Fig. 35 : Trends in area, production and productivity of Rabi Sorghum (1960-2015)

Fig. 36 : Trends in area, production and productivity of Safflower (1960-2015)





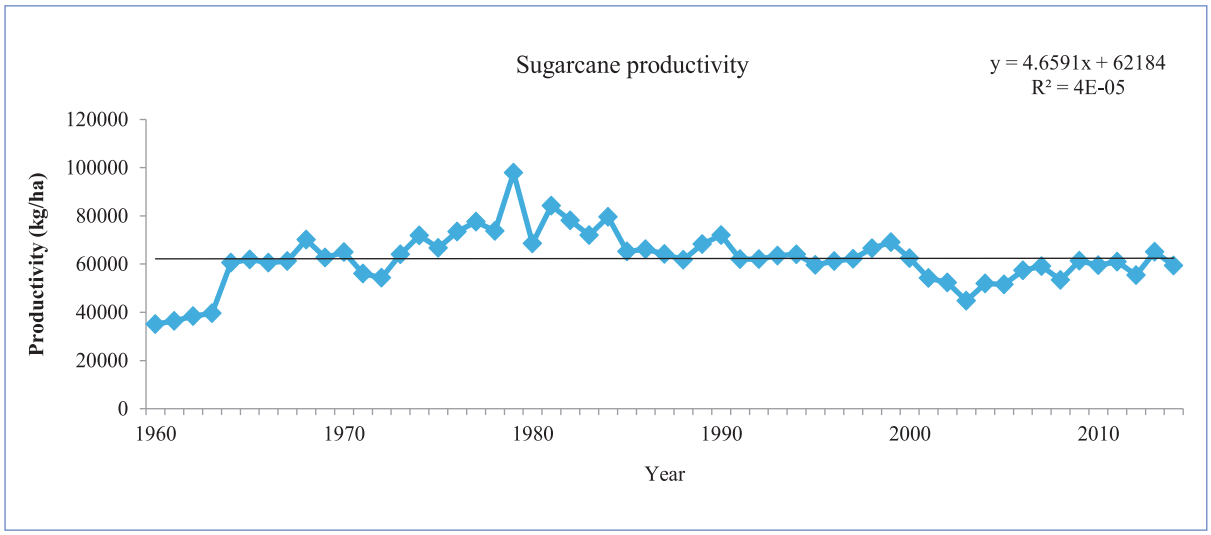


Fig. 37 : Trends in area, production and productivity of Sugarcane (1960-2015)

3.4 Productivity zones of crops of Maharashtra

Yield gap analysis between potential productivity of a region and actual crop yields are necessary. The ultimate target is to tap the maximum potential of a crop from a particular region and do the suitability analysis for that purpose. Though the yield gap analysis is generally done using experimental data, an attempt is made here to identify the regions with low productivity retaining heterogeneity of practical farming at district level. The criteria adopted in the demarcation of the zones are based on area as well as yield of different crops. District are placed in different categories depending on the area and productivity levels. 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 yield gap in different regions.

This comparison may ultimately result in identifying production constraints so as to bring all the zones to higher productivity level. Production constraints can be identified crop diversification efforts can be made to replace the low yielding crops by the high potential crops. The productivity level of crops has to be enhanced and sustained and this is possible only when efficient locations have been identified for the crops. This information would help to replace the uneconomical crop in the identified zones. Criterion adopted for 34 percent districts of Maharashtra are given below for delineation of productivity zones of major field crops in Table 10.

In case of paddy, scope for the improvement of productivity exists in Sangli, Satara, Pune and Nashik districts (Fig.38). Depending upon the availability of water resources, management strategies may have to be evolved to bridge the gap in yield levels. The area under *kharif* sorghum is sufficiently large in Jalgaon and Latur. There is a need to improve its productivity by implementing efficient production techniques in Nanded, Yavatmal, Sangli and Satara districts (Fig. 39). In case of pearl millet area is sufficiently large in Ahmednagar, Nashik and Beed districts. Area and productivity in Jalgaon, Dhule, Pune, Aurangabad districts is medium hence there is large scope to increase area and productivity in these districts by providing suitable varieties performing better under rainfed conditions (Fig. 40). In case of wheat crop, there is large scope to increase productivity in Ahemadnagar, Solapur, Nahsik, Pune, Amravati, Buldana, Nagpur, Beed districts which are high in area but medium in productivity by implementing suitable package of practices (Fig. 47). Area under *rabi* sorghum is more in Solapur, Ahmednagar and Pune districts (Fig. 48). There is great scope to increase productivity of *rabi* sorghum in Dhule, Jalgaon, Akola, Washim, Buldhana and Kolhapur districts.

Production and productivity of pulses like red gram, black gram and green gram indicate that more area under pigeon pea may be encouraged in the Vidarbha and Marathwada districts (Fig. 43). The area of black gram in paddy growing district in konkan region declined 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 Western Maharashtra districts (Fig. 44). However, scope exists to improve the productivity of black gram growing areas in Latur, Nanded and Osmanabad districts. In case of green gram, Akola, Amravati, Buldana and Washim are leading in production (Fig. 45). There is large scope to increase area and production of Dhule, Nandurbar, Nahsik, Pune, Wardha, Aurangabad, Beed and Hingoli districts by implementing pulses development programmmes. Among oilseed crops, groundnut a conventional crop grown largely in Kolhapur, Satara, Pune and Sangli districts (Fig. 41). In Dhule, Nandurbar, Nahsik, Nagpur, Aurangabad, Beed, Latur and Nanded districts yield levels can be improved

through the adoption of rain water conservation and introduction of cultivars which can stand mid-season dry spells as the rainfall is highly erratic in these districts during the SW monsoon season. During recent years, soybean is replacing groundnut in western Maharashtra districts (Fig. 42). Soybean productivity is high in Satara, Sangli, Kolhapur and Pune districts and there is great scope to increase area under this crop. While, Amravati, Nagpur, Washim and Yavatmal and districts have large area but low in productivity hence adoption of proper package of practices for soybean is necessary in these districts.

Productivity levels of sugarcane are highly variable among the major cane growing districts; the low productivity levels in Beed, Jalana, Osmanabad and Parbhani districts require a special attention (Fig. 50). Cotton, another commercial crop shows wide scope for yield improvement in Ahmednagar, Nanded, Buldhana and Yav atmal and to some extent in Jalgaon, Aurangabad and Jalana districts (Fig.46).

Table 10 : Criterion adopted for categorization of productivity zones of major field crops

Sr. No.	Crop	Area ("00"ha)			Yield (Kg/ ha)		
		High	Medium	Low	High	Medium	Low
1	Paddy	>1400	700-1400	<700	>2000	1000-2000	<1000
2	*Kharif* sorghum	>1000	500-1000	<500	>1500	1000-1500	<1000
3	Pearl millet	>1500	600-1500	<600	>750	500-750	<500
4	Ground nut	>400	400-100	<100	>1000	750-1000	<750
5	Soybean	>2000	1000-2000	<1000	>2000	1000-2000	<1000
6	Red gram	>600	300-600	<300	>1000	500-1000	<500
7	Black gram	>300	150-300	<150	>750	500-750	<500
8	Green gram	>300	150-300	<150	>750	500-750	<500
9	Cotton	>2250	800-2250	<800	>500	250-500	<250
10	Wheat	>550	350-550	<350	>2250	1250-2250	<1250
11	Rabi sorghum	>2800	1400-2800	<1400	>1200	600-1200	<600
12	Safflower	>250	100-250	<100	>800	500-800	<500
13	Sugarcane	>900	300-900	<300	>75000	50000-75000	<50000

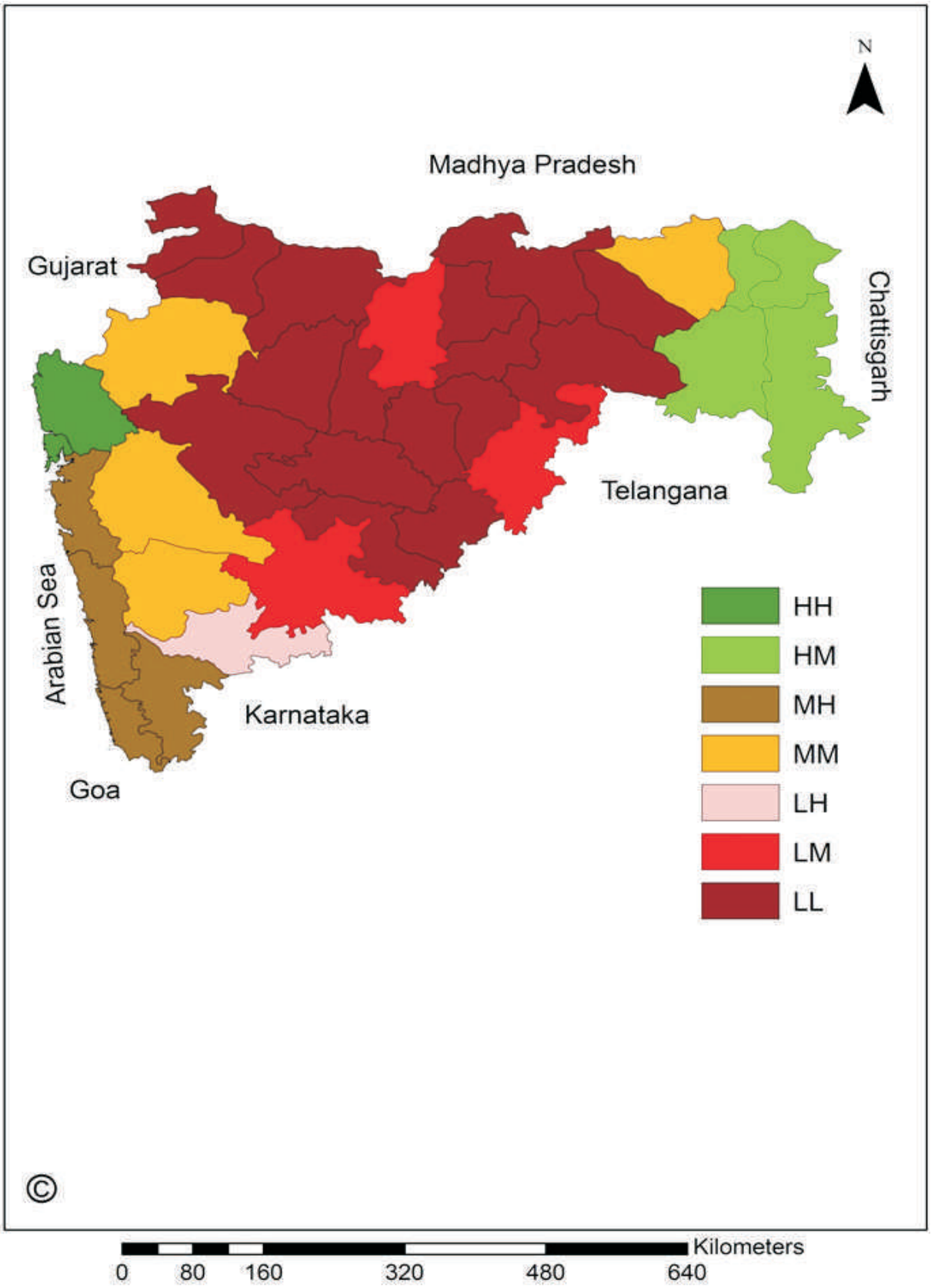


Fig. 38 : Productivity zones of paddy in Maharashtra

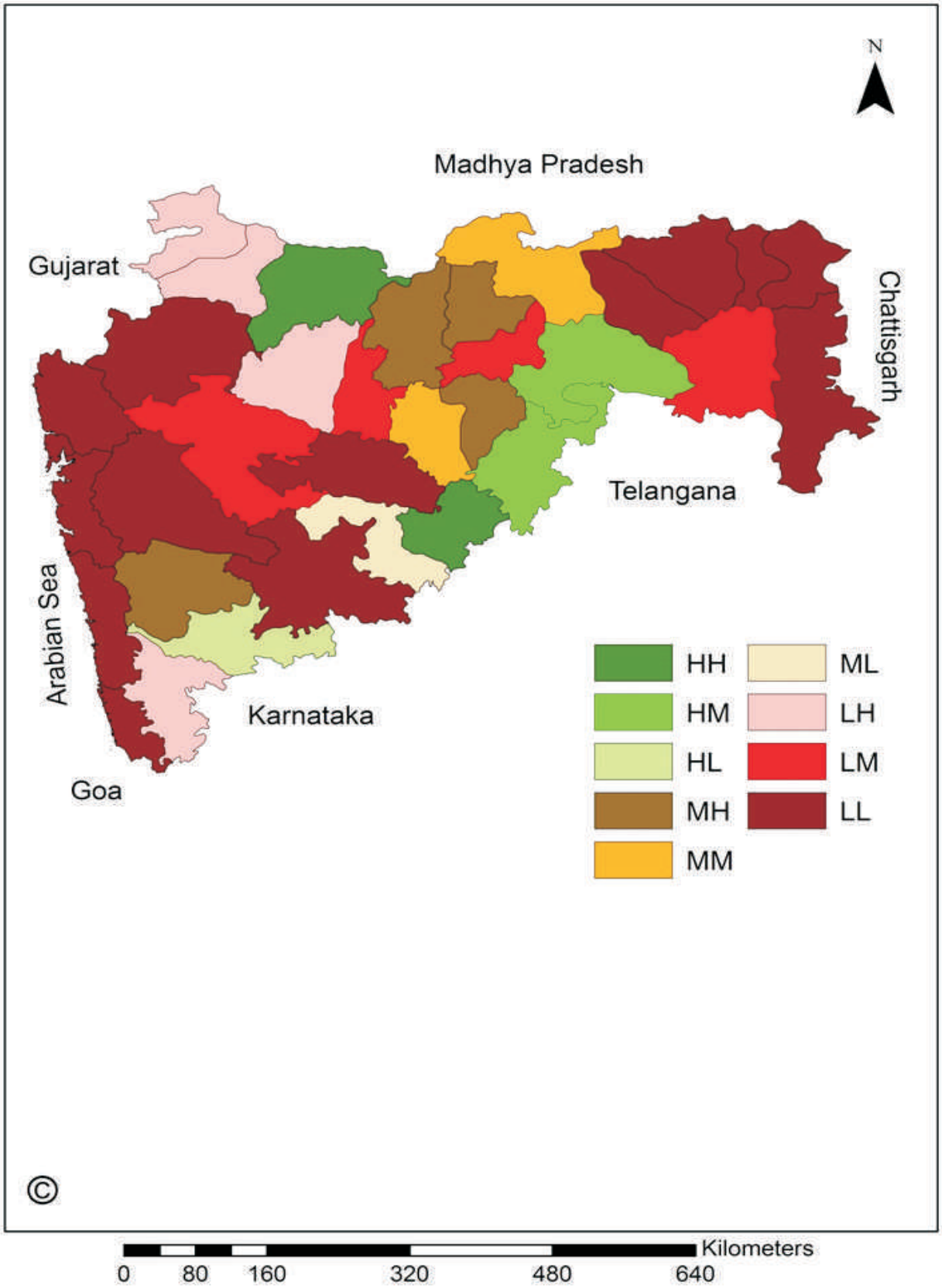


Fig. 39 : Productivity zones of *kharif* Sorghum in Maharashtra

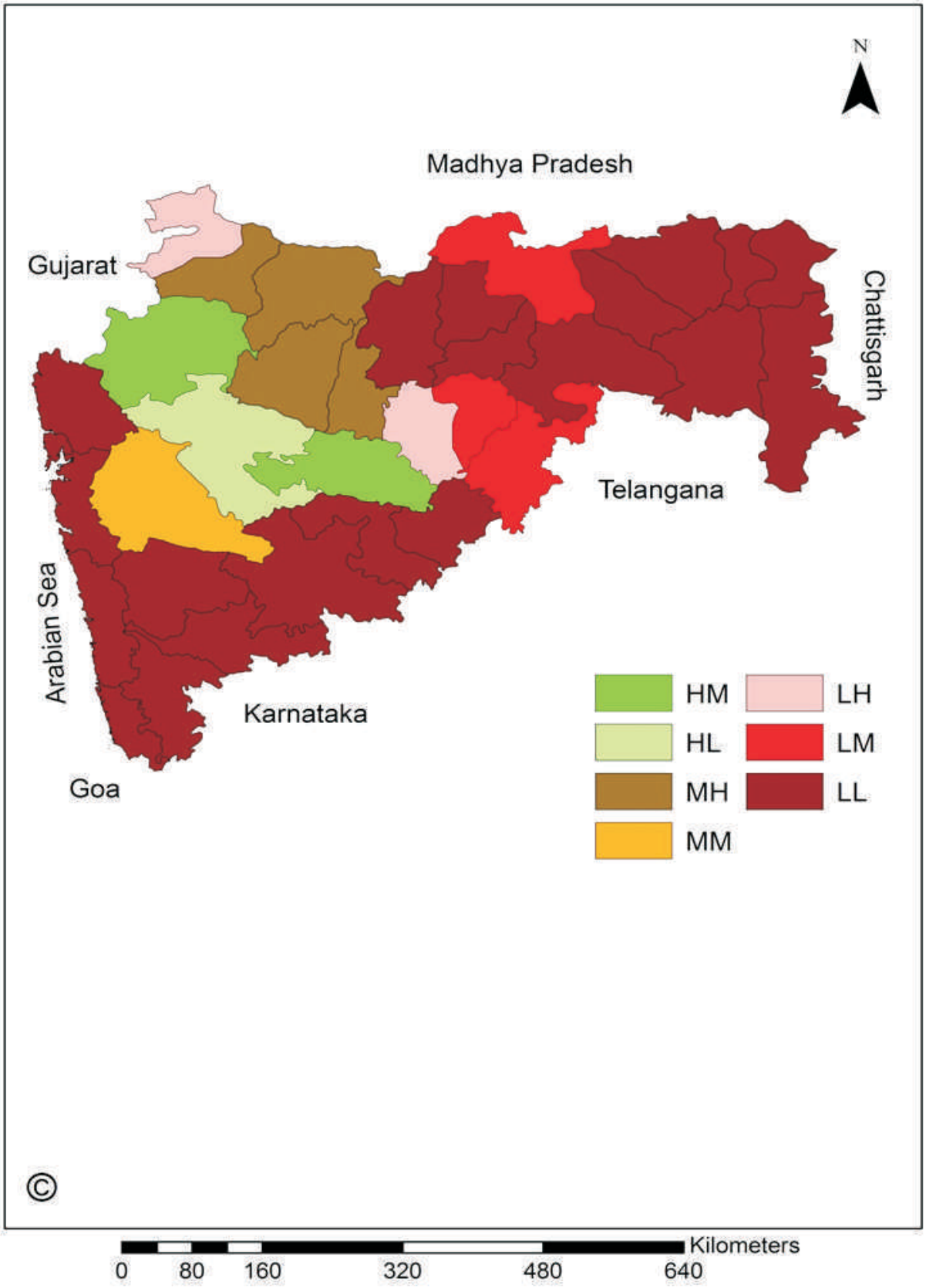


Fig. 40 : Productivity zones of pearl millet in Maharashtra

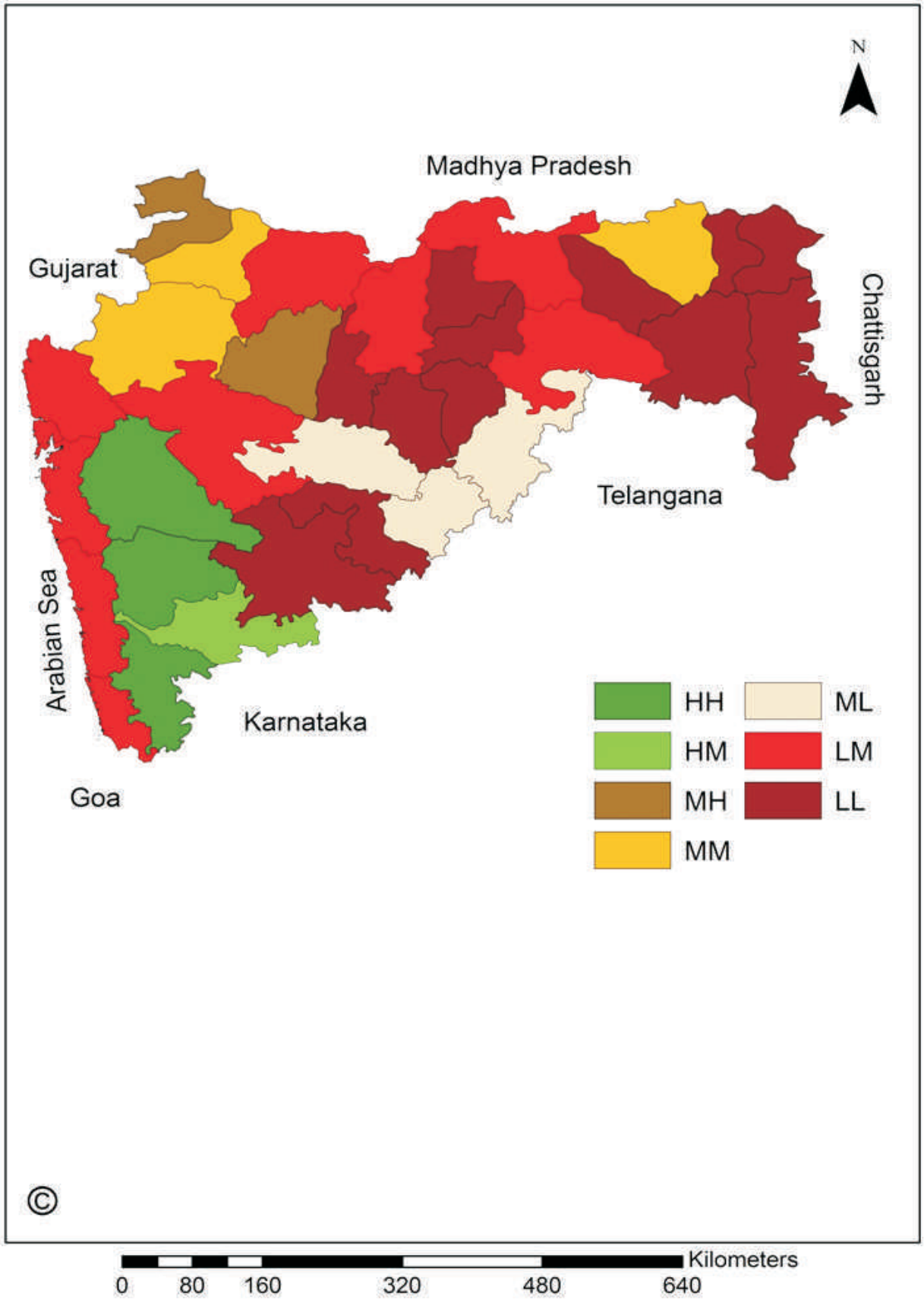


Fig. 41 : Productivity zones of Ground nut in Maharashtra

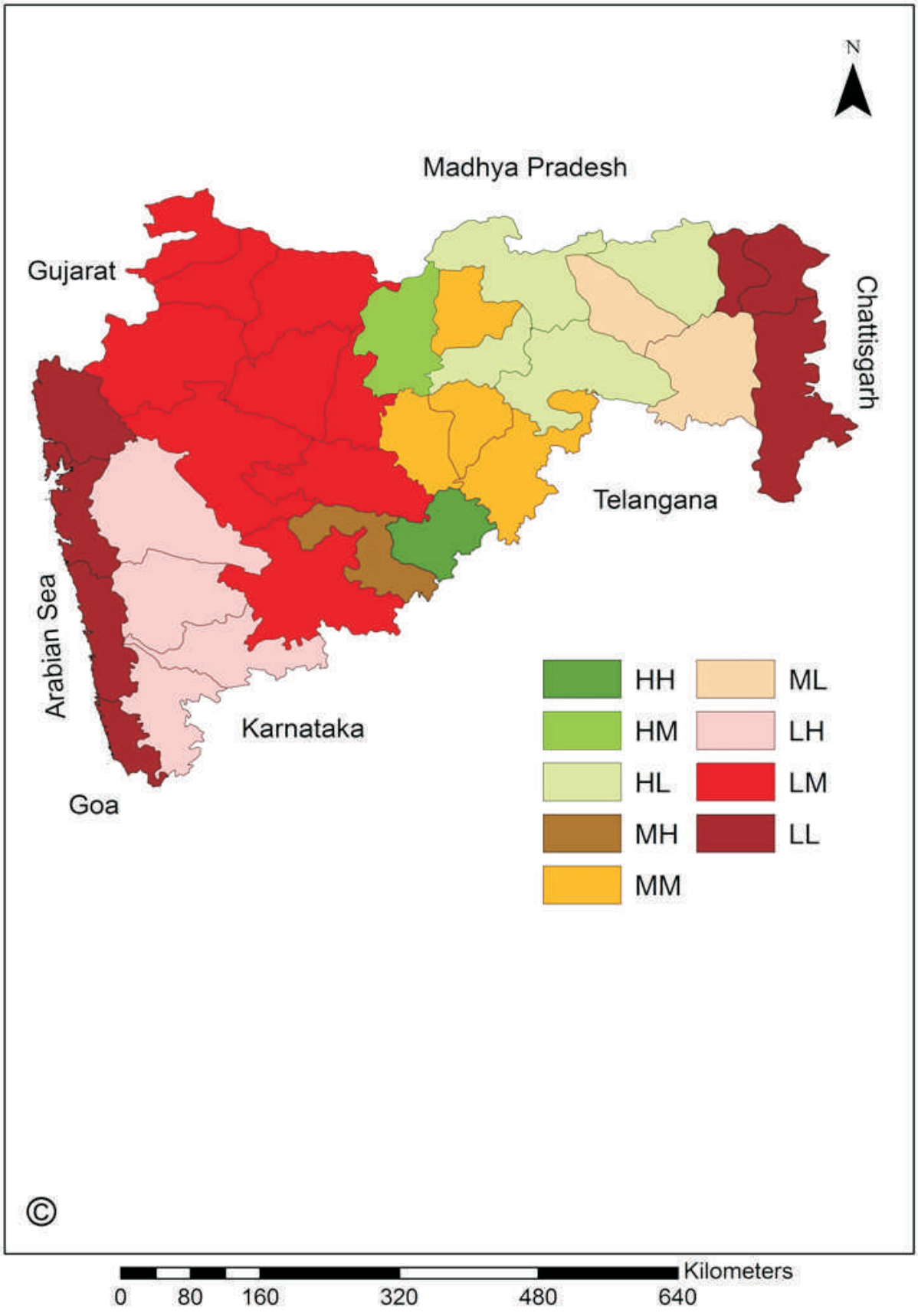


Fig. 42 : Productivity zones of Soybean in Maharashtra

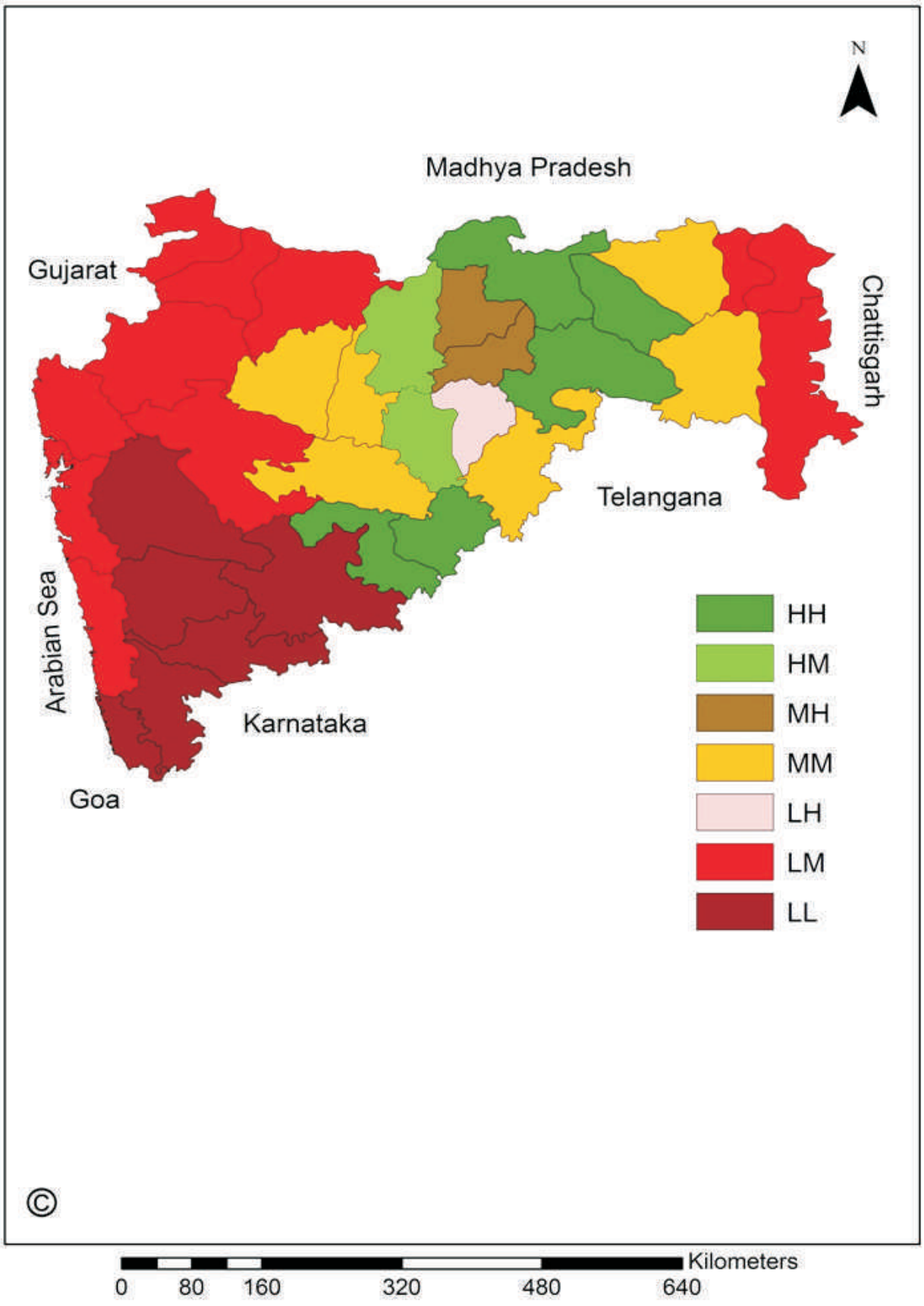


Fig. 43 : Productivity zones of Red gram in Maharashtra

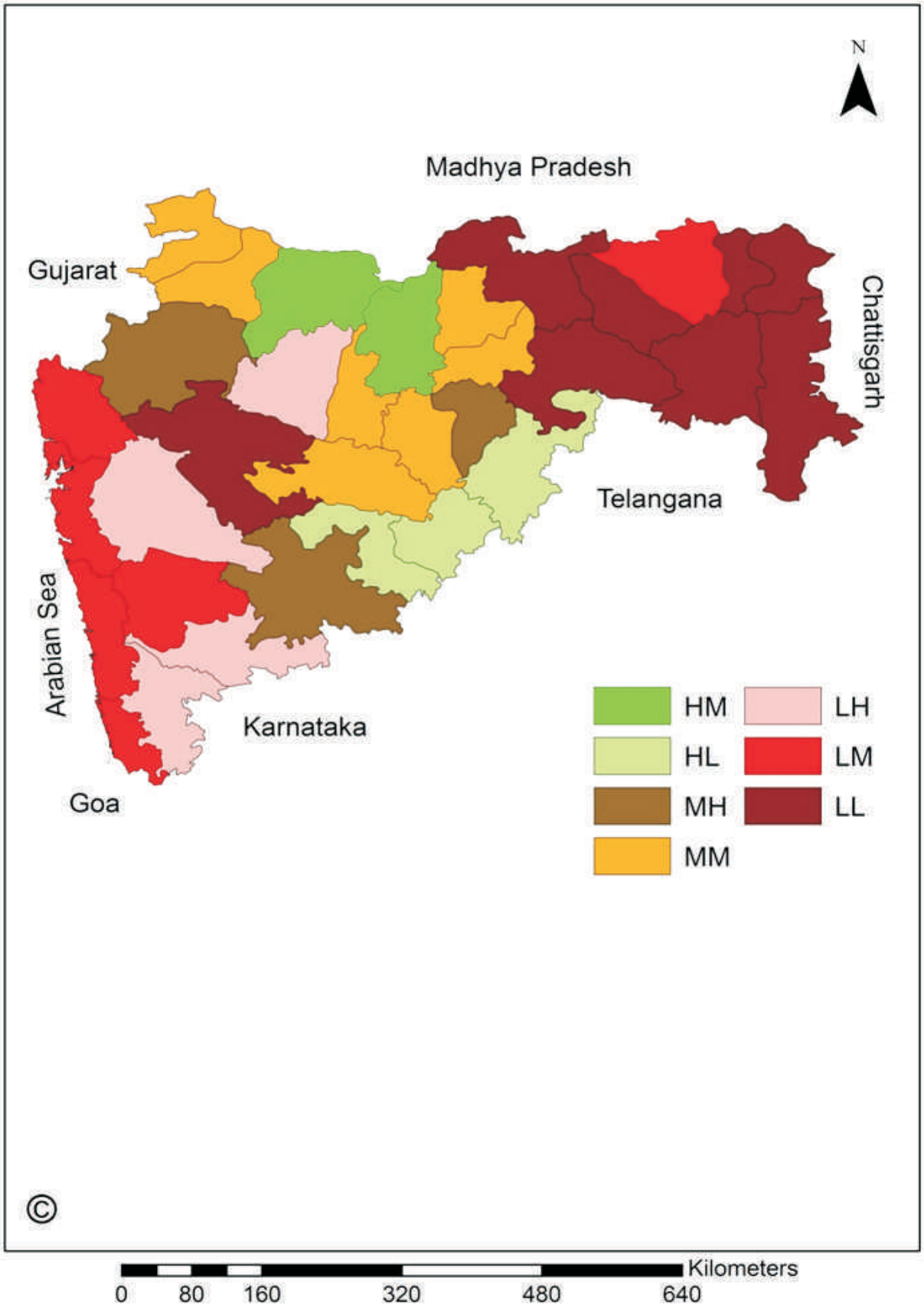


Fig. 44 : Productivity zones of Black gram in Maharashtra

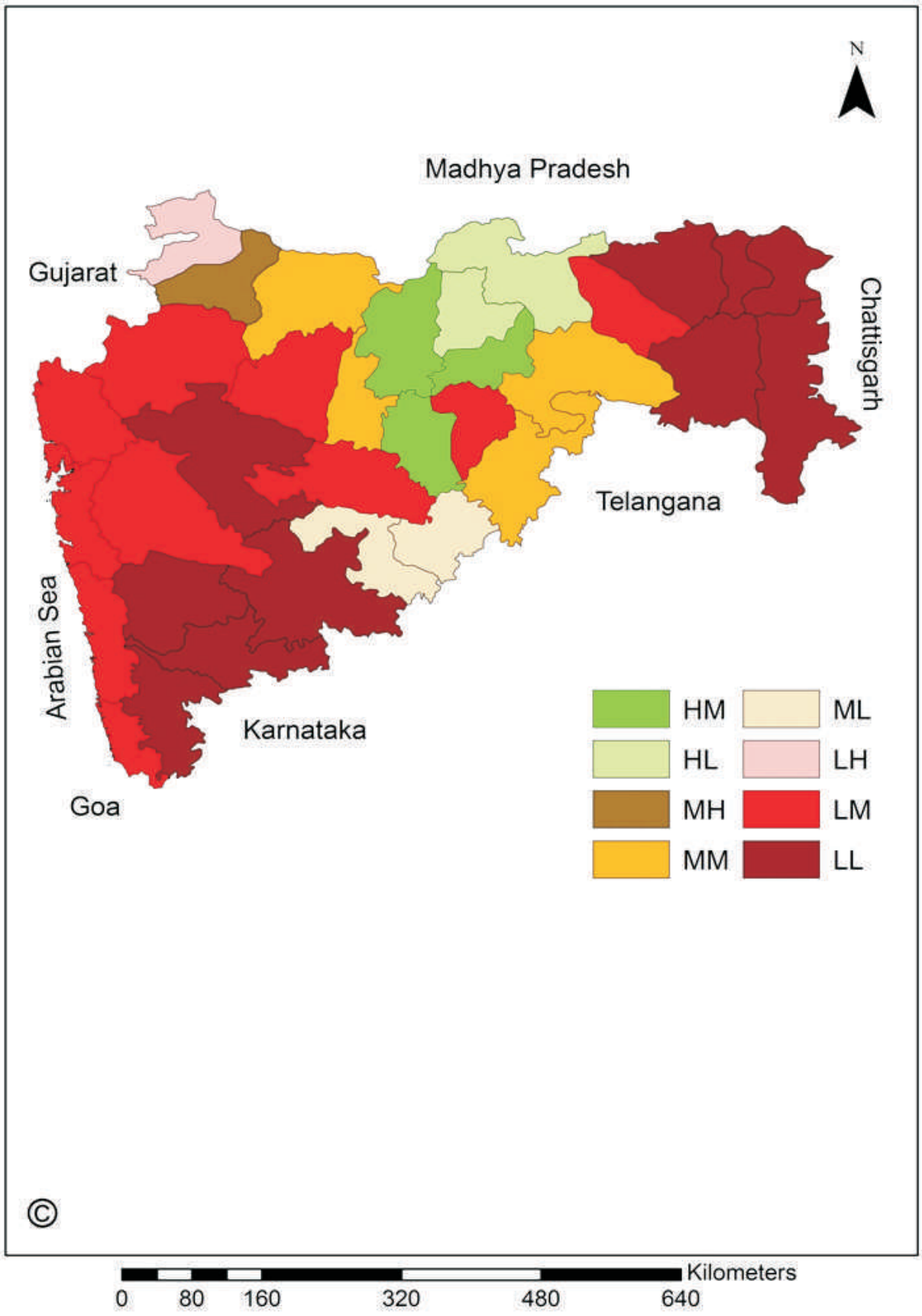


Fig. 45 : Productivity zones of Green gram in Maharashtra

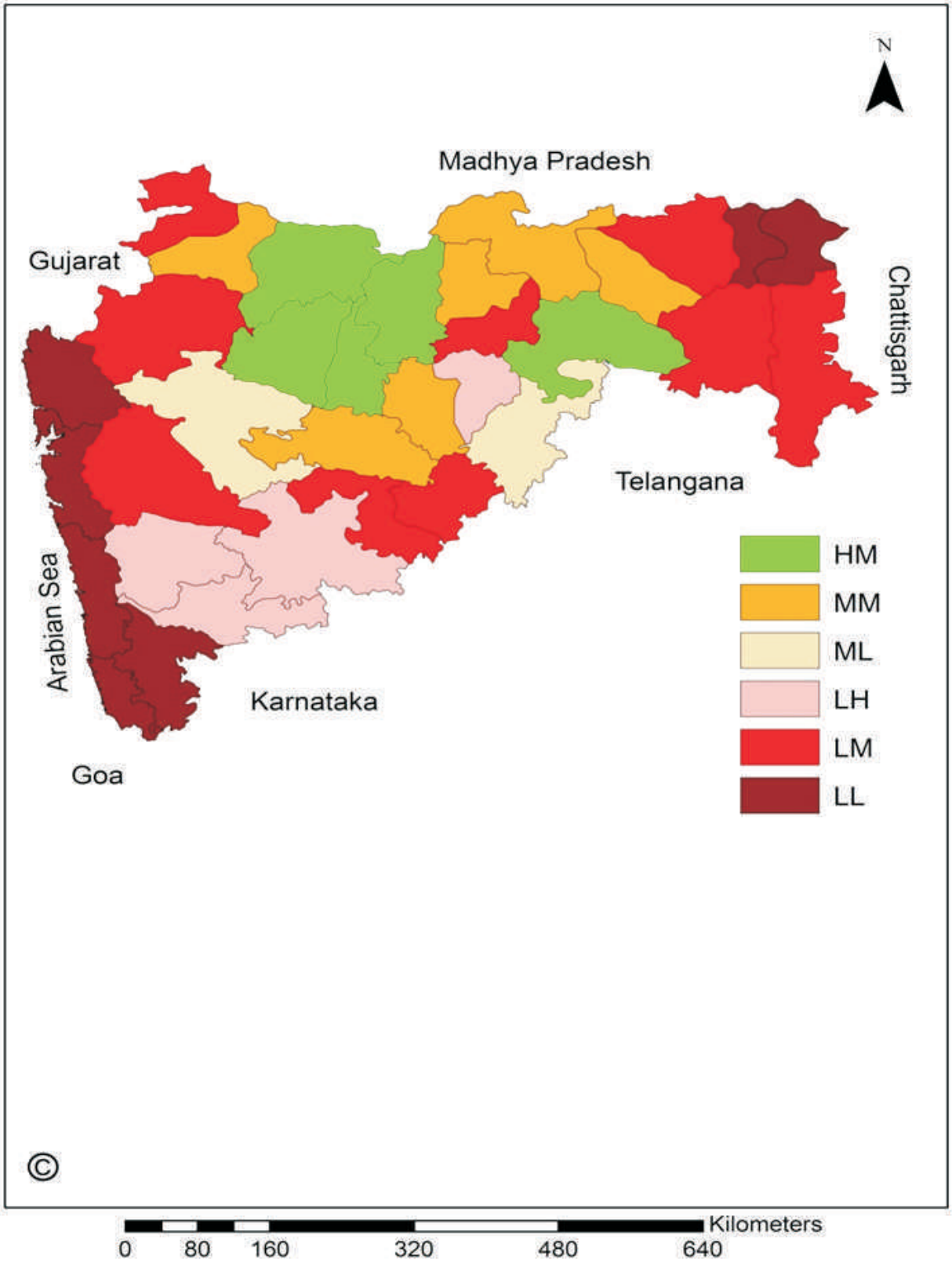


Fig. 46 : Productivity zones of Cotton in Maharashtra

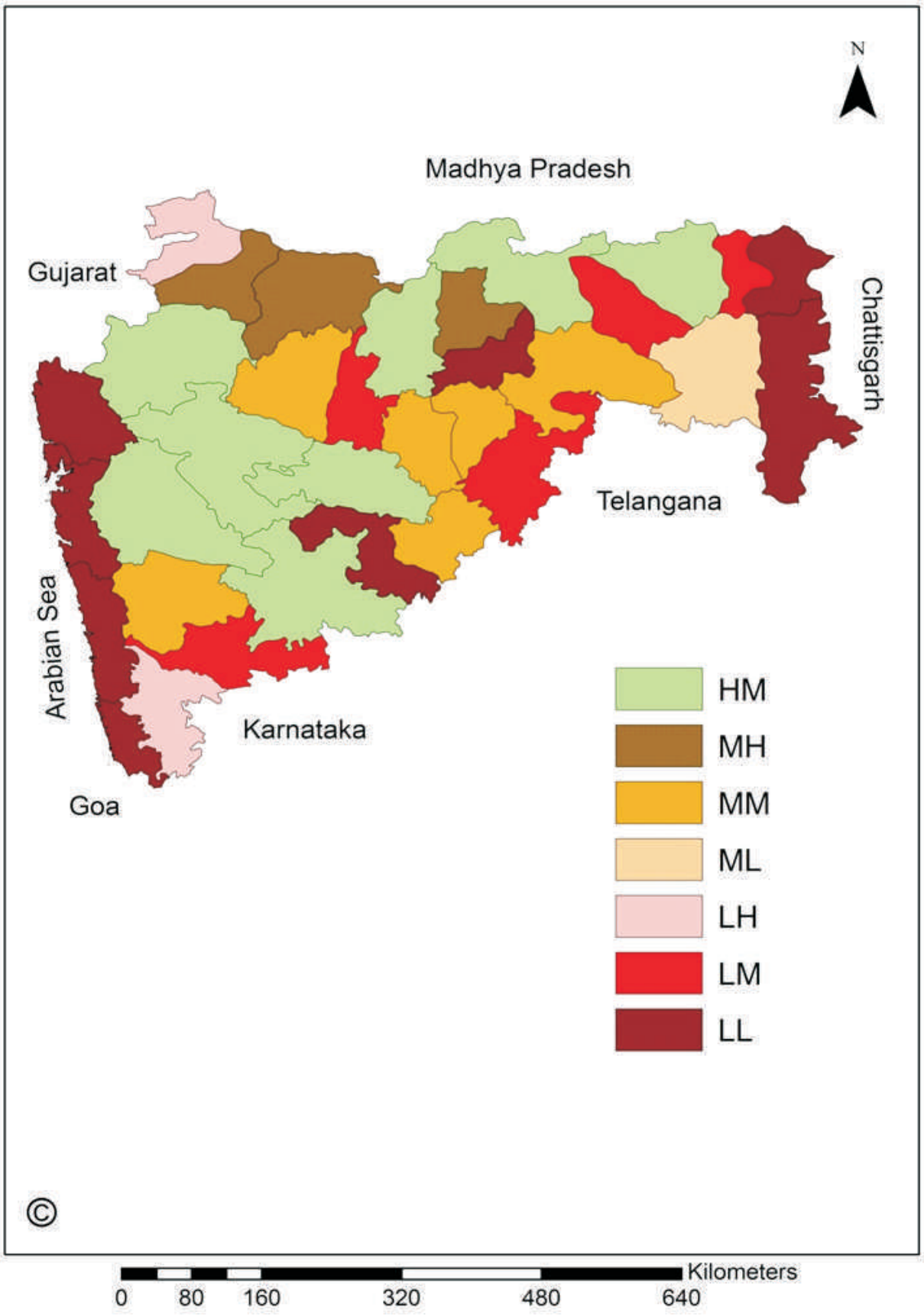


Fig. 47 : Productivity zones of Wheat in Maharashtra

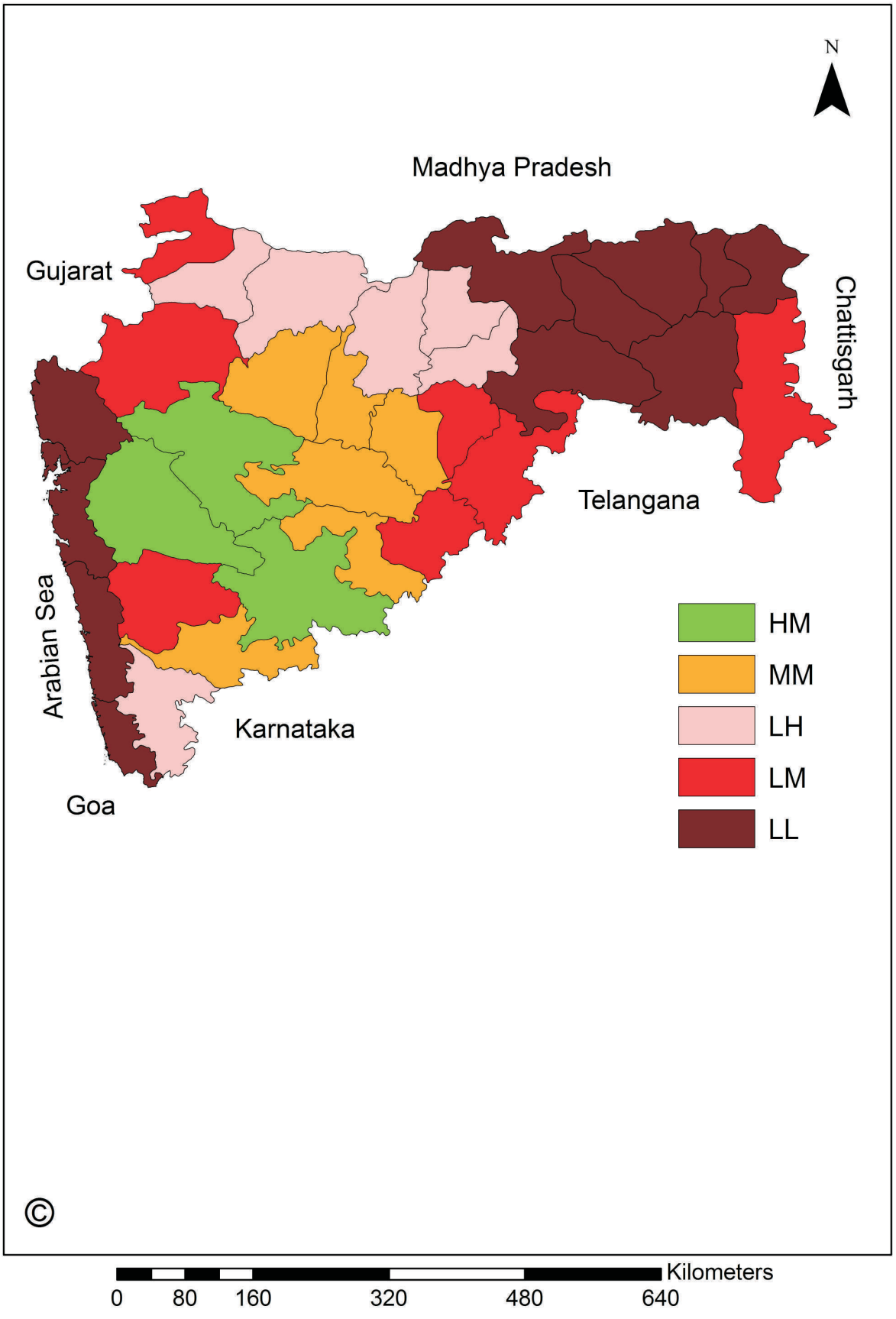


Fig. 48 : Productivity zones of Rabi Sorghum in Maharashtra

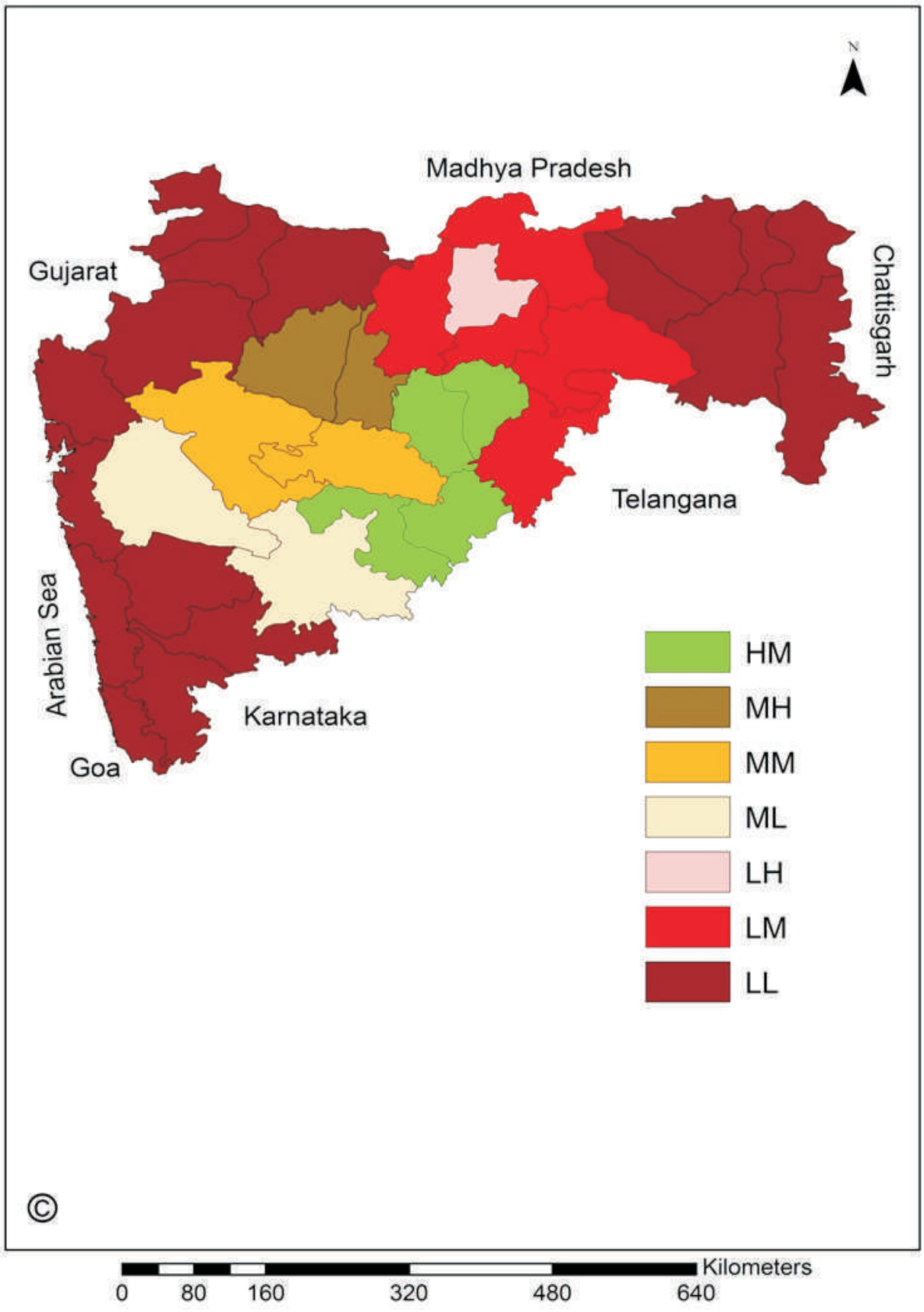


Fig. 49 : Productivity zones of Safflower in Maharashtra

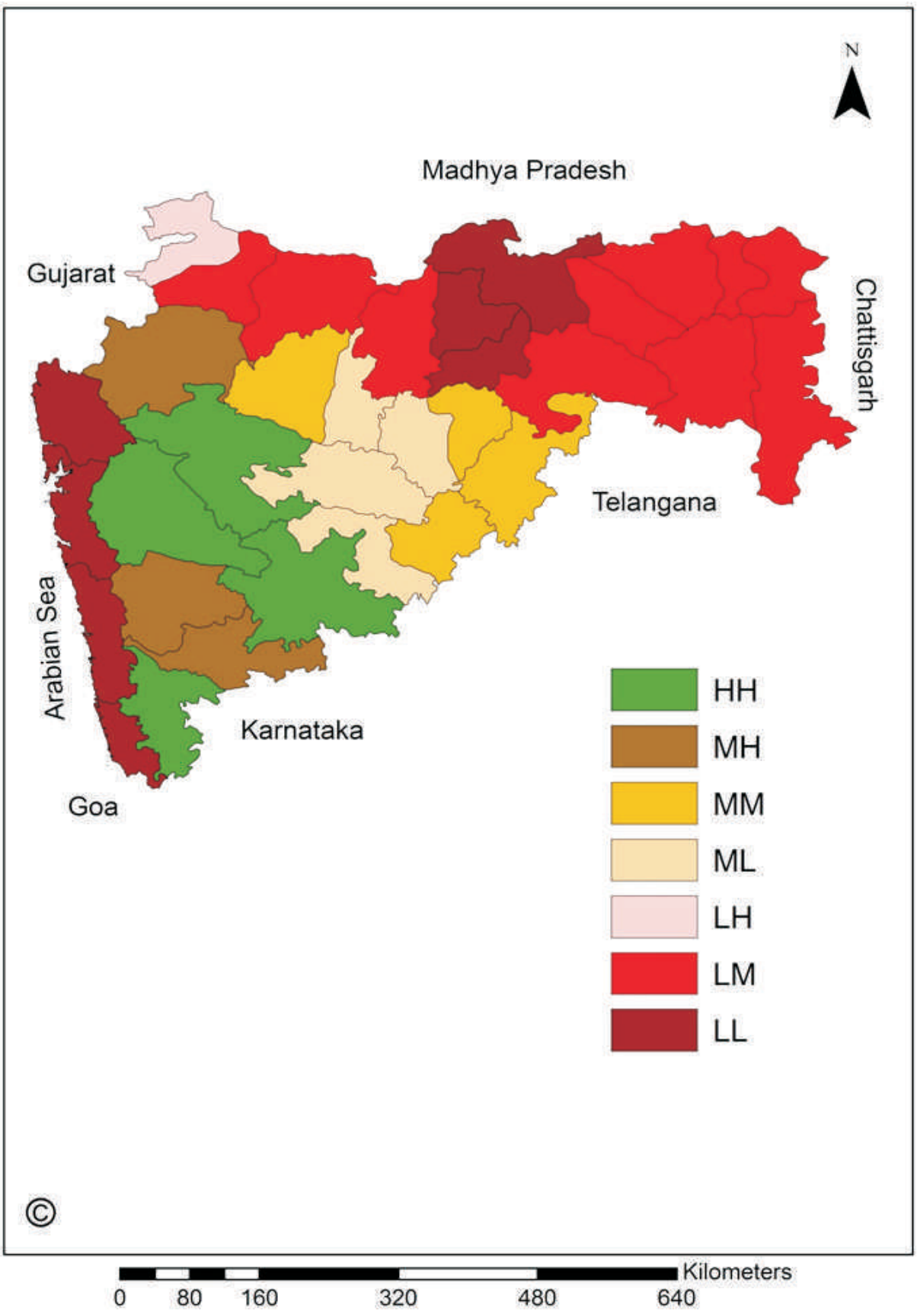


Fig. 50 : Productivity zones of Sugarcane in Maharashtra

3.5. Agrometeorological constraints and opportunities for sustaining production of crops

3.5.1 Paddy

Rice is a water loving plant widely grown during the *kharif* season. Traditionally, rice is grown under continuous flooded condition and requires 1500-2000 mm water (Kandaih, 1985**).** Though principally a tropical crop, rice requires abundance of water (Huke, 1976). Therefore, this factor has a marked bearing on the growth and yield of rice. The onset of monsoon in Maharashtra is around 7th to 15th June in the Konkan region and some western Maharashtra districts. Extends over the entire state by 25th June. The monsoon starts withdrawing from northern parts from mid-September and by 15th October it is completely withdrawn from the entire Maharashtra. In the entire Maharashtra, scarcity of water is a critical limitation for adoption of modern technology for increasing productivity of traditional *rainfed* rice growing areas. Most of the farmers construct huge bunds in the rice fields and impound water for rice cultivation to avoid the uncertainty factor of monsoonal rainfall. This practice of making huge bunds often becomes adverse for rice crop seedlings as higher bunds submerge the rice seedlings and hence growing of tall, long duration, photo-sensitive varieties which can sustain higher water levels has become a common practice of rice cultivation in this area. Farmers in this region grow long duration varieties under broadcast system. These varieties mature by mid-November whereas the south western monsoon withdraws in mid-October. Therefore terminal drought at the reproductive stage is a recurring feature. Under this system, rice seeds are broadcast in a ploughed field immediately after onset of the monsoon around mid-June. *Rabbing* is a practice which consists of burning cow-dung cakes, tree leaves lopping, leaves, grass etc. by making layers on the paddy seed-bed area. *Rabbing* is a sort of partial sterilization of the soil. It improves the physical structure of the soil and increases availability of nutrients in the soil. The practice is, therefore beneficial in raising vigorous seedlings but it involves wastage of valuable organic matter, which can preferably be used in compost making. After about 30 to 35 days of onset of monsoon when sufficient water is impounded in the fields, the fields are ploughed in the standing crop. The puddling operation is done mainly to control weeds, to create semi-puddled conditions, to arrest percolation losses, to decrease the initial high population and to slightly adjust the plant population. Some of the constraints in rice productions envisages both soil and atmosphere condition of region, The soil of rice growing area in the region shows a lot of variation in respect of their physico-chemical properties and hence in nutrient availability. Inadequate coverage under high yielding varieties, poor soil fertility, inadequate and poor water management, low fertilizer use and poor fertilizer use efficiency, incidence of pests and diseases, dry spells at critical stages, poor resource base of farmers, scanty and erratic rains affect rice crop in Maharashtra.

3.5.2 Pulses

The most common problem in pulses is either shortage of rainfall or impeded drainage. Distribution of rainfall is a crucial determinant in determining the final productivity of pulse crops. Pigeon pea and chickpea are the important pulse crops of Maharashtra. Early information about the delayed onset of monsoon helps in the selection of cultivars suitable for reduced LGP. Contingent plans have been developed for the state and emphasis has been laid on growing of pulse crops like pigeon pea, green gram, black gram etc. which can adjust well in the cropping system. This information can also help the concerned departments for 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 some of the districts, advisories on the revival of southwest monsoon season can help the farmers for sowing of pulses on the receipt of rains late in the season. In such situations advisories on varietal selection and pest and disease incidence are crucial.

3.5.3 Oilseeds

Oilseeds are sensitive to stagnation of rainwater and impeded drainage which reduces the yield. 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 received till July, crop alternative to groundnut can be suggested and there are options like niger and sesame in some of the districts. 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 or heavy rains will assist the farmers to undertake measures to mitigate the possible adverse effects on crop. Intercropping of soybean and pigeon is a widely followed practice which give, additional income to farmers.

3.5.4 Cotton

Cotton cultivation in the state is mainly rain fed and subject to vagaries of monsoon. The unpredictability of rainfall leads to low input usage. Cotton is mainly grown on shallow and medium deep soils, which have low available water holding capacity and are highly erosion prone. Most of the rainfall is received during July and August in short and heavy spells, resulting in high runoff and soil loss, and 40-80% of the rain water goes unutilized in the absence of proper soil and water conservation measures. Abiotic factors like cloudy weather, water logging during initial stages, moisture stress at later stages aggravate physiological shedding of buds and bolls. Continuous cultivation of cotton makes it vulnerable for pests, diseases which cause frequent epidemics. Jassids and bollworms are the major pests of cotton. Unfavourable weather conditions affect the timely pest control in the early stages of the crop. Infection by powdery mildew and bacterial blight cause premature crop cessation and reduction in yield. Resource poor farmers rely on credit based input use system in the cotton zone and the pest management advisory role is mainly by pesticide dealers who are not qualified for the job. Early withdrawal of monsoon in some years creates moisture stress and nutrient deficiency in cotton. Any information on the impending early withdrawal could potentially help the farmers to resort 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 through timely and precise agromet advisory services.

3.5.5 Sugarcane

Cane yields are affected by either deficit or excess of moisture. Deficit 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.

3.5.6 Vegetables

During break monsoon conditions, a complex of sucking pests increasingly attack vegetables and crops undergo nutrient and moisture stresses. Issue of agromet advisories well in advance, would facilitate farmers to resort to intercultural operations to conserve soil moisture, timely plant protection and take up foliar application of nutrients to correct any deficiency. If the monsoon rains are considerably delayed, then advisories on early duration vegetable crops/varieties and suitable planting methods will help to sustain the yields.

4. Rainfall Characteristics of Maharashtra

4. Rainfall characteristics

Rain is the primary source of water and any deficit or excess of it during the crop growing season affects their productivity. Commencement and withdrawal of monsoons determines the length of growing period, choice of crop and their cultivars. 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 (except Mumbai district) is furnished in Table 11 and the spatial distribution in Fig. 51. The mean annual rainfall of Maharashta is 1204 ± 358 mm with a coefficient of variation of 36% (Fig. 52). Maharashta is divided into four meteorological sub-divisions *viz., Konkan, Madhya Maharashtra, Marathwada and Vidarbha*. Annual rainfall is highest over coastal *Konkan* region (3039 mm), lowest over *Madhya Maharashtra* (927 mm), *Marathwada* region (630 mm) while it is intermediary over the *Vidarbha* region (1039 mm). There is a large variability in rainfall across the districts in *Konkan* region with Ratnagiri topping the list (3618 mm) followed by Sindhudurg (3292 mm) and Raigad (3082 mm). In *Madhya Maharashtra* region, Kolhapur receives highest rainfall (1894 mm) followed by Satara (1389 mm) and Nashik (1062 mm).While in *Marathwada* region Hingoli receives highest rainfall (737 mm) and Parbhani (649 mm). The rainfall in *Vidarbha* region is found to be higest in Gadchiroli (1479 mm), followed by Gondia (1353 mm), Bhandara (1241 mm), Chandrapur (1198 mm), and Nagpur (1043 mm).

Lowest rainfall was noticed in Ahemadnagar district (547 mm), Jalana (575 mm) and Osmanabad (598 mm) in the state. This is closely followed by Beed (602 mm), Dhule (607 mm), Latur (616 mm), Sangali (617 mm), Solapur (624 mm), Aurangabad (619 mm), Nanded (645 mm), and Parbhani (649 mm). The annual rainfall is highly variable in Nanded district followed by Latur and Parbhani districts. Least variability has been noticed in Palghar and Ratnagiri districts. The rainfall in different seasons, as a percentage, of the total annual rainfall are presented in (Table 12). SWM rainfall accounts for 91% of the annual on a state basis but in *Konkan* and *Vidarbha* region this is 95 and 90% respectively. Rainfall during Post monsoon season is highest in *Marathwada*. Winter and summer rains are negligible in the state.

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 1204 mm is received over 52 rainy days with a variability of 27% (Table 15). Though the annual variability in rainy days is low, it is relatively high during monsoon season. This high variability reflects as intermittent dry spells during continuous wet spells. The numbers of rainy days in different seasons, as per cent, of the total annual rainy days in the four regions of the state are presented in Table 14. The number of rainy days closely follows the total rain fall. On an annual basis, rain occurs more frequently over coastal *Konkan* region (91 days) than *Vidarbha* (49 days), *Madhya Maharashtra* (46 days) and *Marathwada* (35 days). Number of rainy days are high in Sindhudurg districts (102 days) followed by Ratnagiri (100 days), Raigad (91 days), Thane (78 days) and Kolhapur (78 days) and lowest in Ahemadnagar (32 days) followed by Beed, Jalana, Nanded and (33 days) districts

(Fig. 53). An analysis of district-wise occurrences of rain events (Table 15) showed that for the state as a whole, the events are highly variable during the Post monsoon, Winter and Summer seasons compared to SWM season. During the SWM season Nanded had registered highest variability (68%) followed by Latur (59%) and Parbhani (56%) district. Following the trends in variability in rainfall, Ratnagiri district registered least variability in the number of rainy days.

4.3. Features of SWM rainfall

Maharashtra state receives 1090 ± 337 mm rain during SWM season (Table 12). At the district level Ratnagiri receives highest amount of SWM rainfall (3415 mm), Sindhudurg (3048 mm), Raigad (2922 mm) and Palghar (2518 mm) followed by Kolhapur (1677 mm), Gadchiroli (1357 mm), Gondia (1232 mm), Bhandara (1117 mm) and Chandrapur (1083 mm) during SWM period (Fig. 54). Lowest rainfall is noticed in Ahemadnagar district (434 mm), Sangli (445 mm), Solapur (472 mm) and Jalana (498 mm) followed by Osmanabad (506 mm) and Beed (510 mm). Region-wise pattern of rainfall showed that *Konkan* region gets high rainfall (2878 mm) followed by *Vidarbha* (937 mm) and the least is in *Marathwada* (545 mm) while it is intermediary in the *Madhya Maharashtra* (799 mm) on an average.

Region-wise lowest variability is seen in coastal *Konkan* (24%), *Vidarbha* (30%) and highest in *Marathwada* (61%) and it is intermediate over *Madhya Maharashtra* (36%). At the district level, highest variability in the monsoon rainfall is observed in Nanded district (81 %) followed by Latur (67 %) and Parbhani (65 %) lowest in Palghar and Ratnagiri (23 %) and Akola and Chandrapur districts (7%) (Fig. 55).

On an average, SWM rainfall in the state is spread over 45 days. At the regional level highest number of rainy days are observed in the *Konkan* region (83 days) and *Vidarbha* (43 days) and lowest over the *Marathwada* region (30 days) and these are intermediate over *the Madhya Maharashtra* (39 days). At the district level, Ratnagiri and Sindhudurg districts recoded maximum number of rainy days (91 days) followed by Raigad (84 days) and these were least in Ahemadnagar (26 days) and Solapur (28 days) (Fig. 56).

4.4. Features of Post monsoon rainfall

Rainfall during Post monsoon for the entire state is 85± 78 mm with a variability of 98%, which is almost two times more than the variability observed for the monsoon season rainfall. Coastal *Konkan* receives large amount of rainfall (134 mm) mainly in the Sindhudurg, Ratnagiri and Raigad districts. *Madhya Maharashtra* and *Marathwada* receives a fairly good amount of rainfall (96 mm) and (71 mm) respectively the lowest Post monsoon rainfall is noticed in the *Vidarbha* region (64 mm).Thus, it can be inferred that chances of receiving rainfall over *Vidarbha* and *Marathwada* are relatively less. Among the districts, Sindhudurg, receives high rainfall (196 mm) during this season followed by Ratnagiri (172 mm) and it is lowest in Nandurbar (46 mm) and Dhule (56 mm) districts (Fig. 57).

4.5. Features of summer and winter rainfall

The mean summer rainfall for the state is 23 ± 36 mm. At the regional level, *Madhya Maharashtra* get more rainfall (30 mm) than *Konkan* (28 mm), Vidarbha (23 mm) and Marathwada region (11 mm). The districts Kolhapur (76 mm), Sangli (53 mm) and Satara (49 mm) receive high rainfall whereas the lowest is in Nandurbar (7 mm), Aurangabad, Jalana and Latur (8 mm) (Fig. 60). The summer season rainfall over the state is spread over only 2 rainy days but among the districts it ranged from two to four (Table 11).

Rain during winter season is very meagre / insignificant and on an average the state receives 1 mm only. Thus, the winter season can be called as the driest. Highest rainfall is received in districts Gondia (26 mm) and Bhandara (22 mm) in the *Vidarbha* and in *Konkan* it is paltry (Ratnagiri – 0.0 mm;) (Fig. 61).

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 15. July is the wettest month in the state (370 mm) followed by August (296 mm), June (233 mm) and September (191 mm) in that order (Table 15). Albeit, highest rainfall is received during July, rainfall during September is associated with least variability (50%) indicating its consistency. At the district level also July rainfall is dominant in 33 out of 34 districts (Fig. 63 a to l).

It is not the total amount of rainfall on a monthly basis that is vital, but the numbers of rainy days in a month determine the distribution of rain and its effectiveness. District-wise average number of rainy days on a monthly basis are furnished in the Table 18. It may be observed that highest frequency is noticed during July (18 days) followed by August (16 days) and June (11 days) (Fig. 68). Amongst the 34 districts in the state, 22 districts showed highest number of rainy days during July.

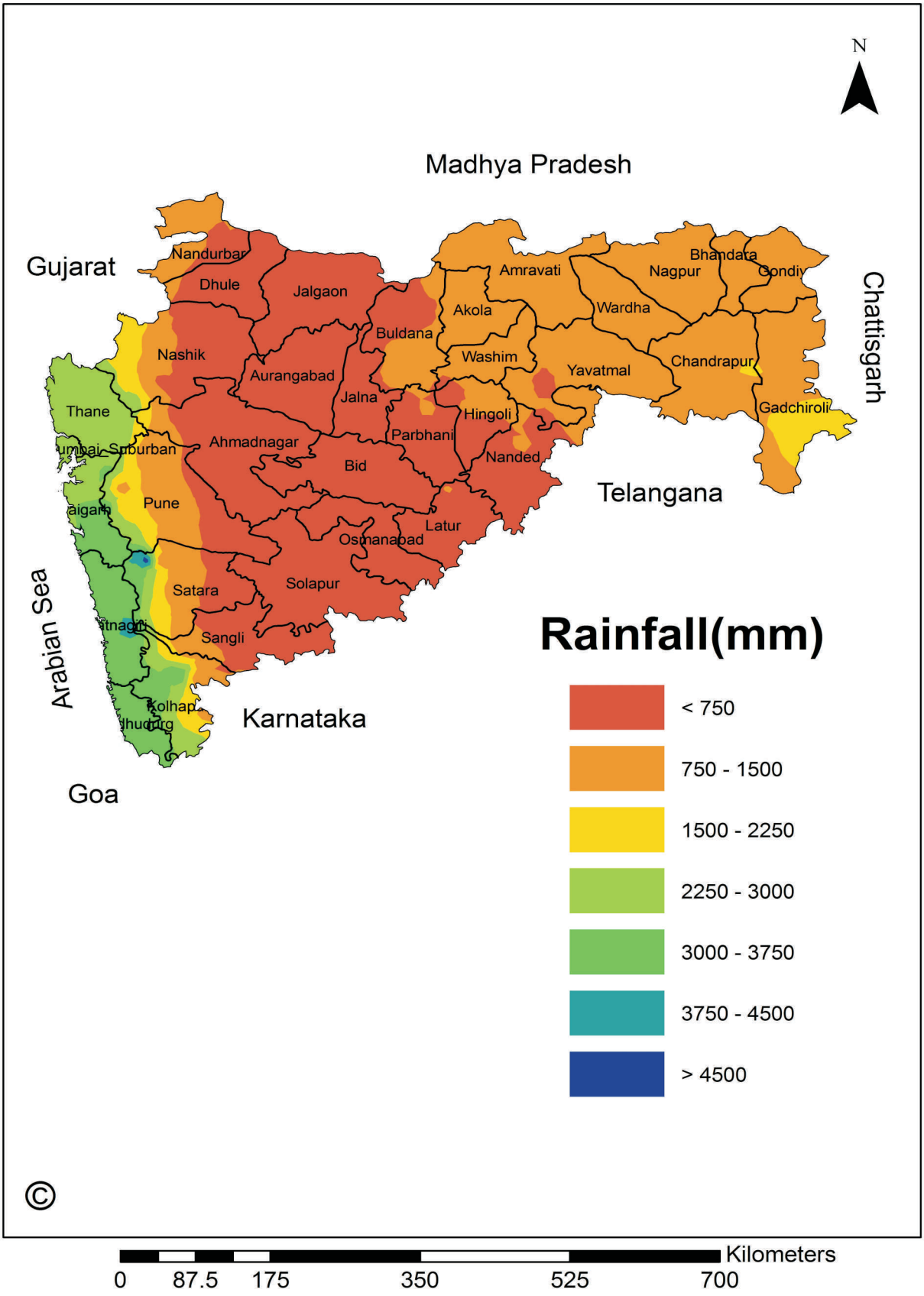


Fig. 51: Annual rainfall (mm) over Maharashtra

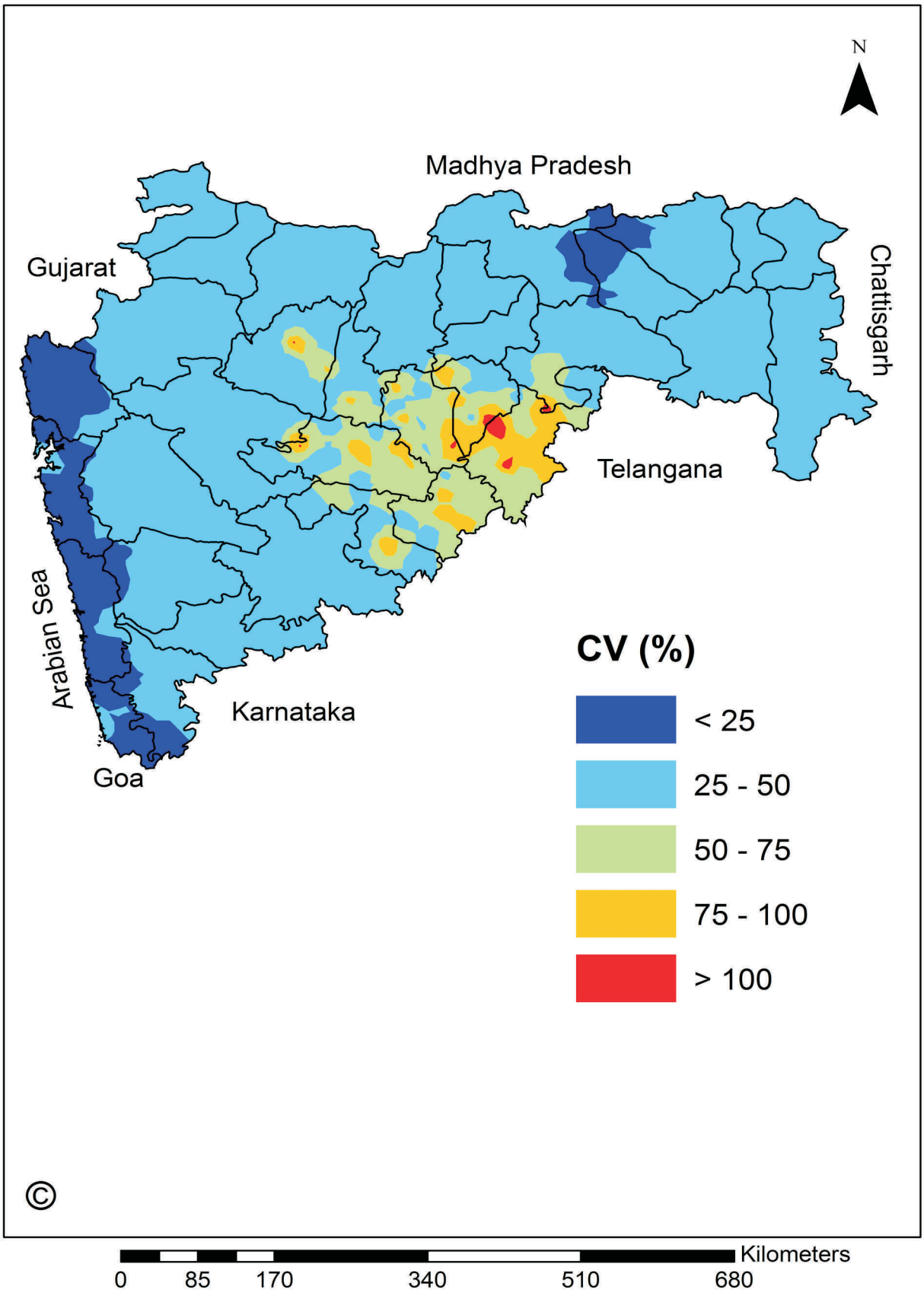


Fig. 52: Variability (CV%) in annual rainfall (mm) over Maharashtra

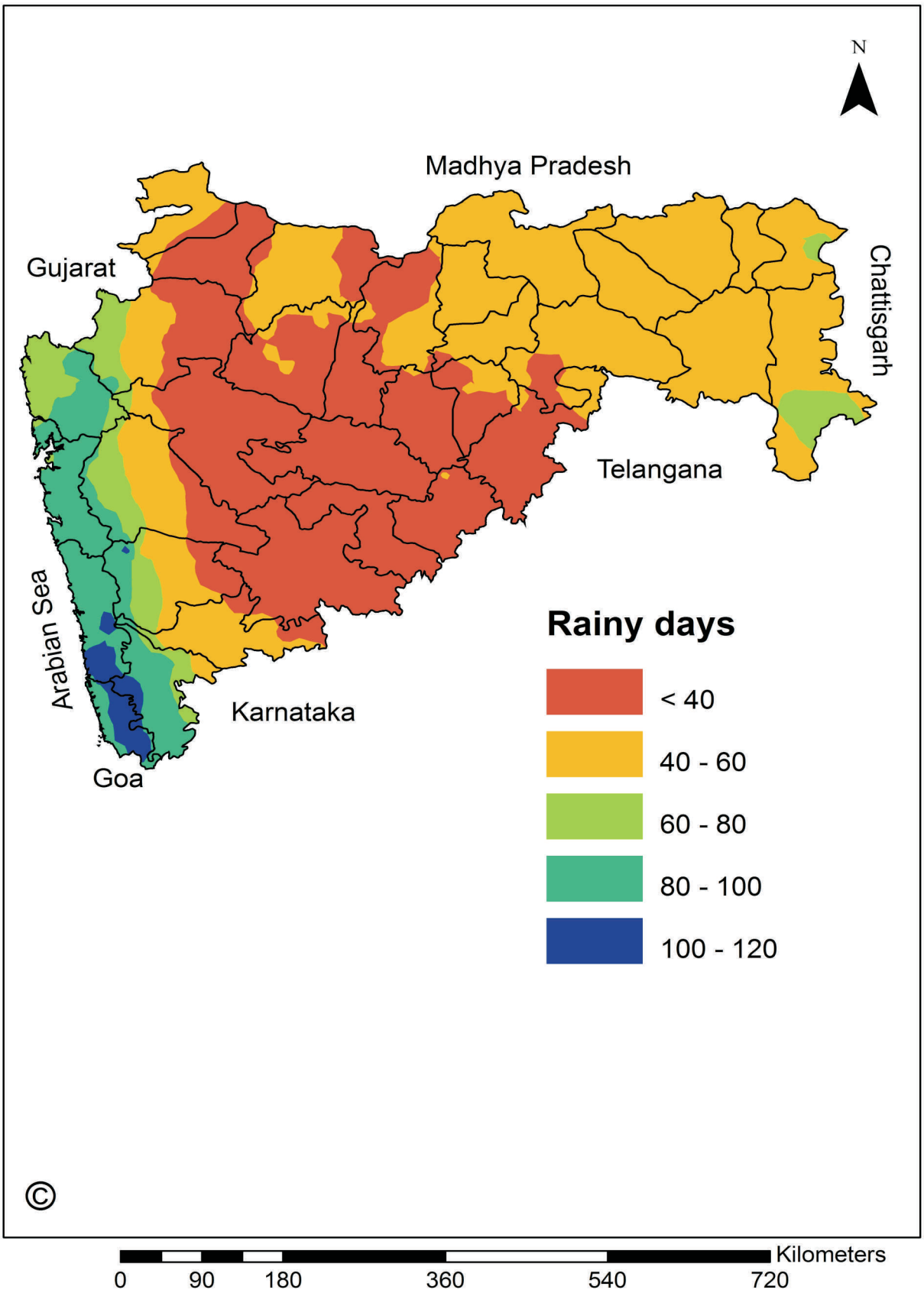


Fig. 53 : Annual number of rainy days in Maharashtra

Table 11: District wise mean annual and seasonal rainfall (mm) with its standard deviation (mm) and coefficient of variation (%)

District	Annual			Southwest			Post monsoon			Summer			Winter		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
Ahemadnagar	547	176	32	434	166	38	89	74	82	22	35	161	2	7	359
Dhule	607	175	29	537	165	31	56	57	104	12	22	185	3	8	340
Jalgaon	702	227	32	621	216	35	64	67	104	11	21	181	6	12	214
Kolhapur	1894	480	28	1677	440	31	140	91	65	76	78	103	2	7	401
Nandurbar	898	326	36	845	323	38	46	46	102	7	18	277	1	3	345
Nashik	1062	328	32	961	320	35	87	73	85	13	24	189	2	5	355
Pune	929	356	36	797	351	42	108	90	83	23	38	171	1	3	365
Sangali	617	190	32	445	168	39	117	75	65	53	54	106	2	6	358
Satara	1389	373	30	1204	354	35	135	99	74	49	48	100	2	6	335
Solapur	624	221	36	472	190	40	113	87	76	34	39	120	5	12	251
Palghar	2615	585	22	2518	577	23	83	83	101	14	39	277	0	1	109
Raigad	3082	707	23	2922	705	24	124	107	88	34	63	183	0	2	320
Ratnagiri	3618	797	22	3415	782	23	172	143	86	31	67	207	0	2	234
Sindhudurg	3292	776	24	3048	726	24	196	173	91	48	89	186	1	2	122
Thane	2590	617	23	2486	644	26	93	93	100	11	31	286	0	1	100
Aurangabad	630	195	37	529	178	39	80	80	106	8	20	244	2	6	290
Beed	602	293	57	510	270	62	78	77	106	12	29	243	2	5	335
Hingoli	737	366	61	659	336	62	60	62	120	13	28	215	5	12	274
Jalana	575	267	55	498	239	56	68	72	114	8	19	243	1	4	454
Latur	616	346	66	526	305	67	79	77	110	8	20	248	3	9	287
Nanded	645	432	80	567	387	81	59	68	136	11	30	269	8	26	326
Osmanabad	598	269	53	506	241	56	76	68	96	15	26	178	2	6	304
Parbhani	649	345	64	562	304	65	68	79	132	15	28	194	4	11	267
Akola	782	228	29	689	214	31	68	63	93	14	28	220	11	21	222
Amravati	881	242	28	790	229	29	63	61	96	16	27	184	12	24	207
Bhandara	1241	331	27	1117	302	27	67	71	106	33	39	119	22	38	170
Buldhana	742	221	30	654	206	31	70	79	114	11	25	236	6	13	236
Chandrapur	1198	378	32	1083	333	31	73	67	92	26	36	142	15	31	214
Gadchiroli	1479	464	31	1357	420	31	76	69	92	32	45	144	14	32	32
Gondia	1353	377	28	1232	343	28	59	66	110	36	42	118	26	42	162
Nagpur	1043	294	28	950	279	29	51	53	104	26	38	150	16	30	197
Wardha	967	224	23	868	223	26	57	53	93	28	34	125	14	27	198
Washim	871	259	29	775	245	31	65	64	97	21	38	179	10	18	182
Yavatmal	874	302	35	794	283	36	56	52	96	13	22	212	12	27	238
State	**1204**	**358**	**36**	**1090**	**337**	**38**	**85**	**78**	**98**	**23**	**36**	**188**	**6**	**14**	**259**

Table 12: Annual rainfall distribution in different regions and rainfall in different seasons as per cent of annual

	Rainfall (mm)					% of annual rainfall			
	Annual	Post monsoon	Southwest	Summer	Winter	Post monsoon	Southwest	Summer	Winter
Konkan	3039	134	2878	28	1	4	95	1	1
Madhya Maharashtra	927	96	799	30	3	10	86	3	1
Marathwada	630	71	545	11	3	11	87	2	1
Vidarbha	1039	64	937	23	14	6	90	2	1
State	**1204**	**85**	**1090**	**23**	**6**	**7**	**91**	**2**	**1**

Table14: Region-wise and season-wise distribution of annual rainy days and as per cent of annual

	Rainy days					% of annual rainy days			
	Annual	Post monsoon	Southwest	Summer	Winter	Post monsoon	Southwest	Summer	Winter
Konkan	90	6	83	1	0	7	91	1	0.2
Madhya Maharashtra	46	5	39	2	0	11	85	4	1
Marathwada	38	4	30	1	3	11	86	3	10
Vidarbha	49	3	43	2	1	6	88	4	2
State	**52**	**5**	**45**	**1**	**1**	**10**	**87**	**2**	**2.3**

Table 13: District wise mean annual and seasonal rainy days with its standard deviation and coefficient of variation (%)

District	Annual			Post monsoon			Southwest			Summer			Winter		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
Ahemadnagar	32	8	26	5	3	61	26	7	29	1	2	157	0	1	330
Dhule	34	8	24	3	3	83	30	7	25	1	2	173	0	1	298
Jalgaon	41	9	23	4	3	89	36	9	24	1	2	158	0	1	194
Kolhapur	77	11	15	8	4	48	65	9	16	4	3	88	0	0	375
Nandurbar	46	11	23	3	2	90	42	11	25	1	1	215	0	0	341
Nashik	49	11	23	5	3	64	44	10	24	1	1	169	0	0	346
Pune	48	11	24	6	3	62	41	11	27	2	2	165	0	0	354
Sangali	42	10	26	7	3	52	32	10	30	3	3	97	0	0	259
Satara	57	10	19	7	4	53	46	9	22	3	3	89	0	0	301
Solapur	37	9	25	6	3	54	28	8	28	3	2	105	0	1	206
Palghar	84	11	13	5	4	77	78	10	13	0	1	220	0	0	105
Raigad	91	10	12	6	4	72	84	10	12	1	2	151	0	0	289
Ratnagiri	100	10	10	7	5	66	91	9	10	1	2	168	0	0	179
Sindhudurg	102	12	12	9	5	58	91	11	12	2	3	133	0	0	59
Thane	78	10	13	4	3	81	73	10	13	1	1	228	0	0	54
Aurangabad	38	11	35	5	3	81	32	10	36	1	2	234	0	1	290
Beed	33	13	48	4	3	91	28	11	49	1	2	234	0	1	310
Hingoli	36	14	51	3	3	110	32	13	51	1	2	221	0	1	248
Jalana	33	13	48	4	3	93	29	12	49	1	2	244	0	0	448
Latur	35	17	59	4	3	94	30	15	59	1	2	258	0	1	253
Nanded	33	18	69	3	3	115	29	16	68	1	2	242	0	1	270
Osmanabad	36	13	44	5	3	83	30	11	45	1	2	171	0	1	284
Parbhani	33	15	56	3	3	108	29	13	56	1	2	192	0	1	235
Akola	41	8	21	4	3	88	35	8	23	1	2	207	1	1	203
Amravati	45	9	21	3	3	82	39	9	22	1	2	171	1	1	187
Bhandara	57	11	19	4	4	100	49	8	17	3	3	111	1	2	135
Buldhana	39	8	20	3	3	88	34	7	21	1	2	240	0	1	218

Chandrapur	53	10	20	4	3	79	46	8	18	2	2	120	1	1	171
Gadchiroli	59	11	18	4	3	80	52	9	17	2	2	125	1	1	180
Gondia	59	11	19	4	4	100	51	9	17	3	3	101	2	2	112
Nagpur	51	8	16	3	2	86	45	7	15	2	3	139	1	2	172
Wardha	49	8	17	3	2	80	42	8	19	2	3	116	1	1	166
Washim	45	9	20	3	3	77	39	9	23	2	2	165	1	1	170
Yavatmal	44	10	22	3	3	91	40	9	22	1	2	197	1	1	209
State	**51**	**11**	**27**	**4**	**3**	**80**	**45**	**10**	**28**	**2**	**2**	**171**	1	**1**	**234**

Table 15: Average monthly rainfall in different districts of Maharashtra

District	Jan	Feb	Mar	April	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Ahemadnagar	1	1	3	3	16	102	97	96	139	65	20	4
Dhule	1	1	4	1	8	118	172	135	113	35	16	5
Jalgaon	3	3	5	1	6	119	189	185	129	41	16	7
Kolhapur	1	1	7	20	50	368	651	453	205	112	22	5
Nandurbar	1	0	1	1	5	147	297	244	157	32	11	2
Nashik	1	1	1	2	10	172	319	278	193	63	20	3
Pune	1	0	3	4	16	181	248	200	168	84	21	3
Sangli	1	1	6	9	38	110	111	98	126	97	17	2
Satara	1	1	4	13	32	247	436	329	192	100	27	8
Solapur	3	2	4	8	22	96	97	112	168	88	21	5
Thane	0	0	2	0	9	485	935	700	366	80	12	0
Raigadh	0	0	2	3	29	659	1100	757	407	109	15	1
Ratnagiri	0	0	4	0	27	891	1229	822	473	152	20	1
Sindhudurg	1	0	7	2	39	873	1100	682	393	166	29	0
Palghar	0	0	1	0	13	497	943	704	374	73	10	0
Aurangabad	2	1	5	1	2	112	134	141	141	55	18	7
Beed	1	1	4	2	6	108	121	130	152	64	10	4
Hingoli	3	2	5	2	7	150	199	182	127	50	7	3
Jalana	1	0	4	1	3	106	138	134	120	52	12	4
Latur	2	1	4	2	2	91	146	147	143	69	8	2
Nanded	6	2	5	2	4	108	176	169	114	50	7	2
Osmanabad	1	1	4	4	7	97	123	122	164	64	10	3
Parbhani	3	1	7	2	5	108	163	161	130	58	7	2
Akola	7	4	8	2	4	144	218	211	115	51	14	4
Amravati	7	5	8	1	6	147	258	243	142	47	13	4
Buldhana	4	2	7	2	3	128	200	194	133	53	15	3
Chandrapur	9	6	10	7	9	196	369	338	180	63	7	3
Gadchiroli	10	4	10	12	11	237	465	441	214	64	9	3
Gondia	15	11	15	11	10	205	434	394	200	42	10	7
Nagpur	8	8	12	6	8	177	330	271	171	35	14	2
Wardha	8	6	10	4	14	172	292	248	156	42	12	3
Washim	6	4	13	4	4	166	241	216	152	52	11	3
Yavatmal	10	3	6	3	4	165	268	227	135	44	10	2
State	**4**	**2**	**6**	**4**	**13**	**233**	**370**	**296**	**191**	**68**	**14**	**3**
SD	4	2	4	4	12	212	324	209	96	31	6	2
CV	108	115	62	108	94	91	88	71	50	46	41	61

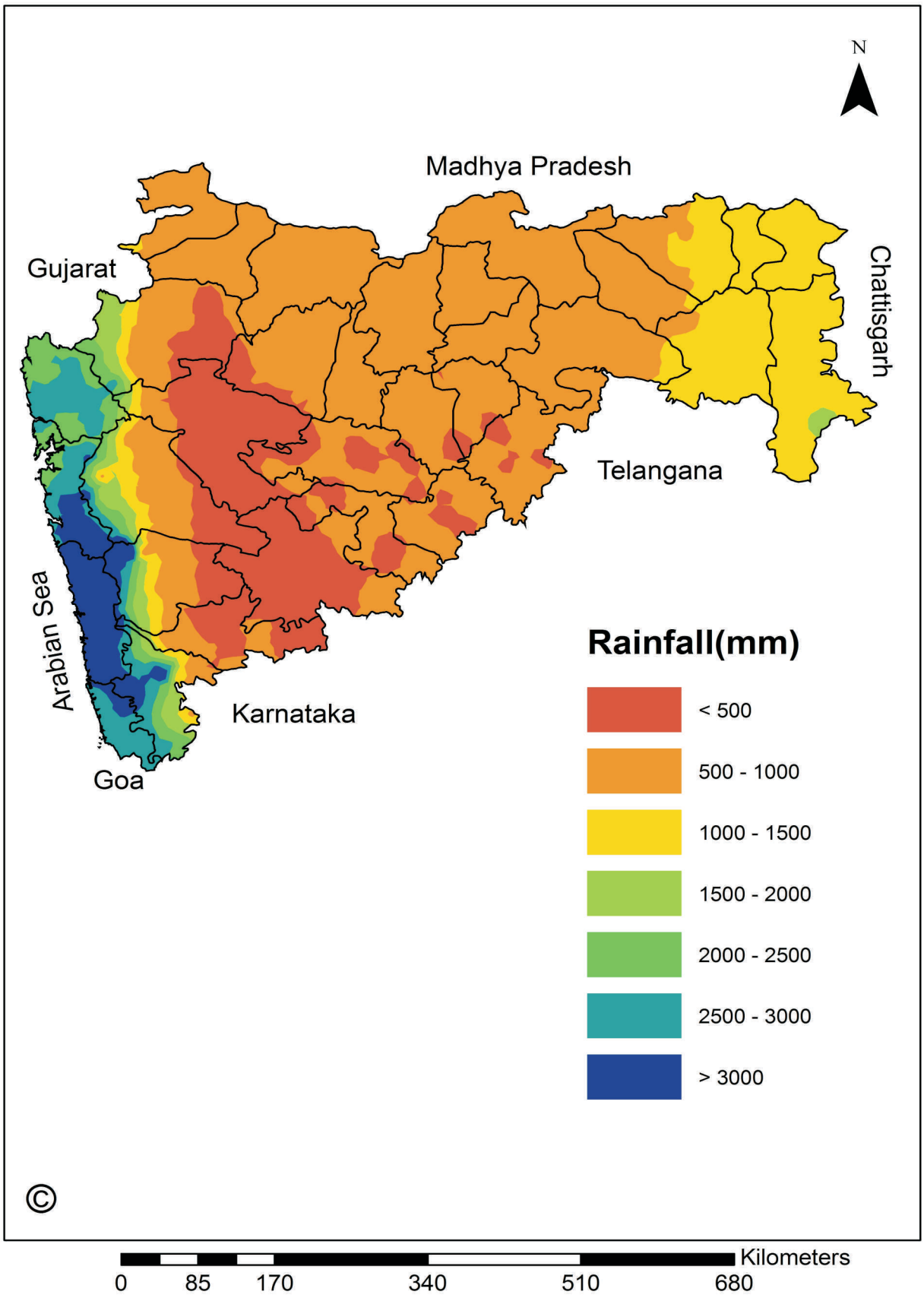


Fig. 54 : SWM rainfall (mm) over Maharashtra

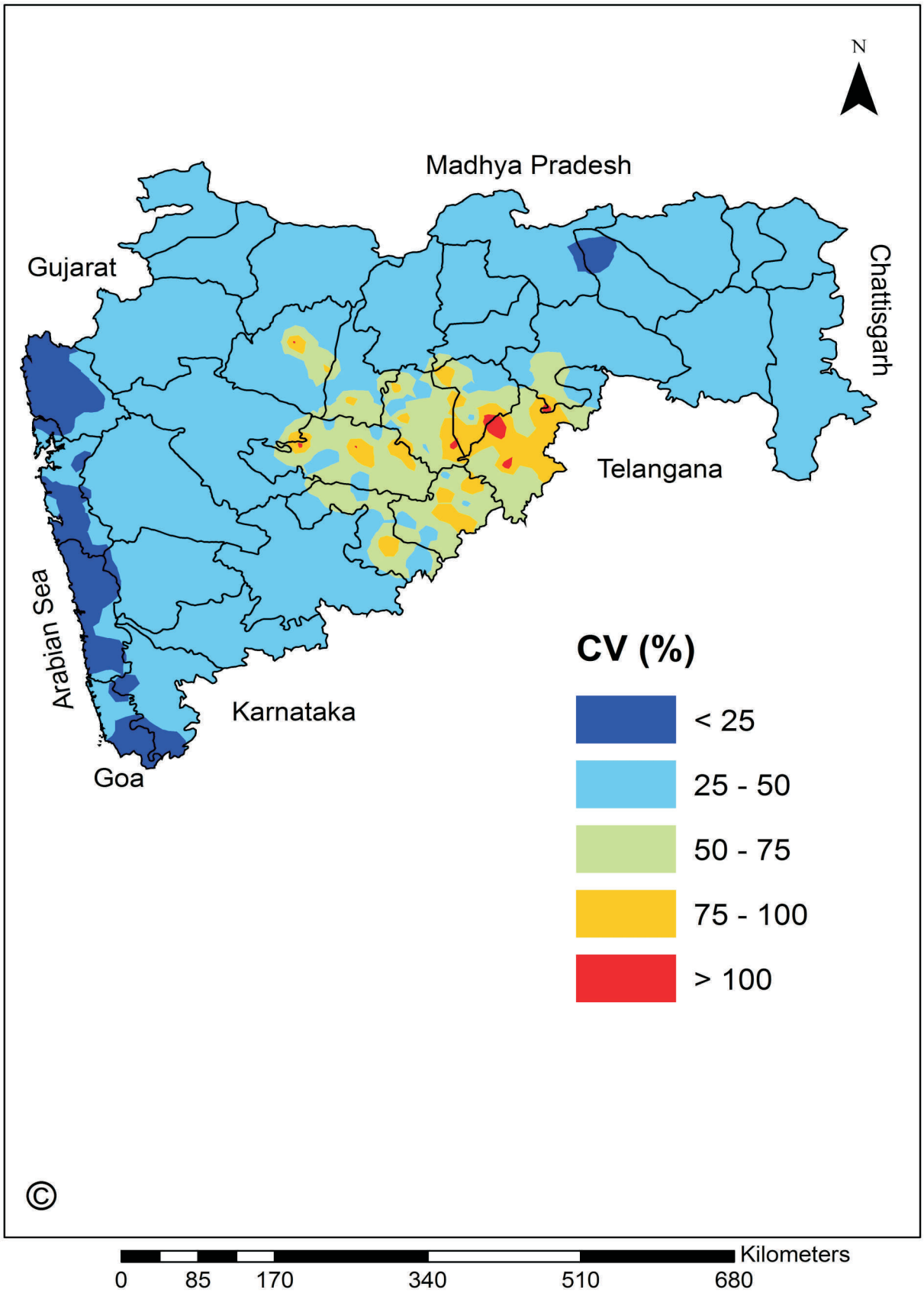


Fig. 55 : Variability (CV %) in SWM rainfall (mm) over Maharashtra

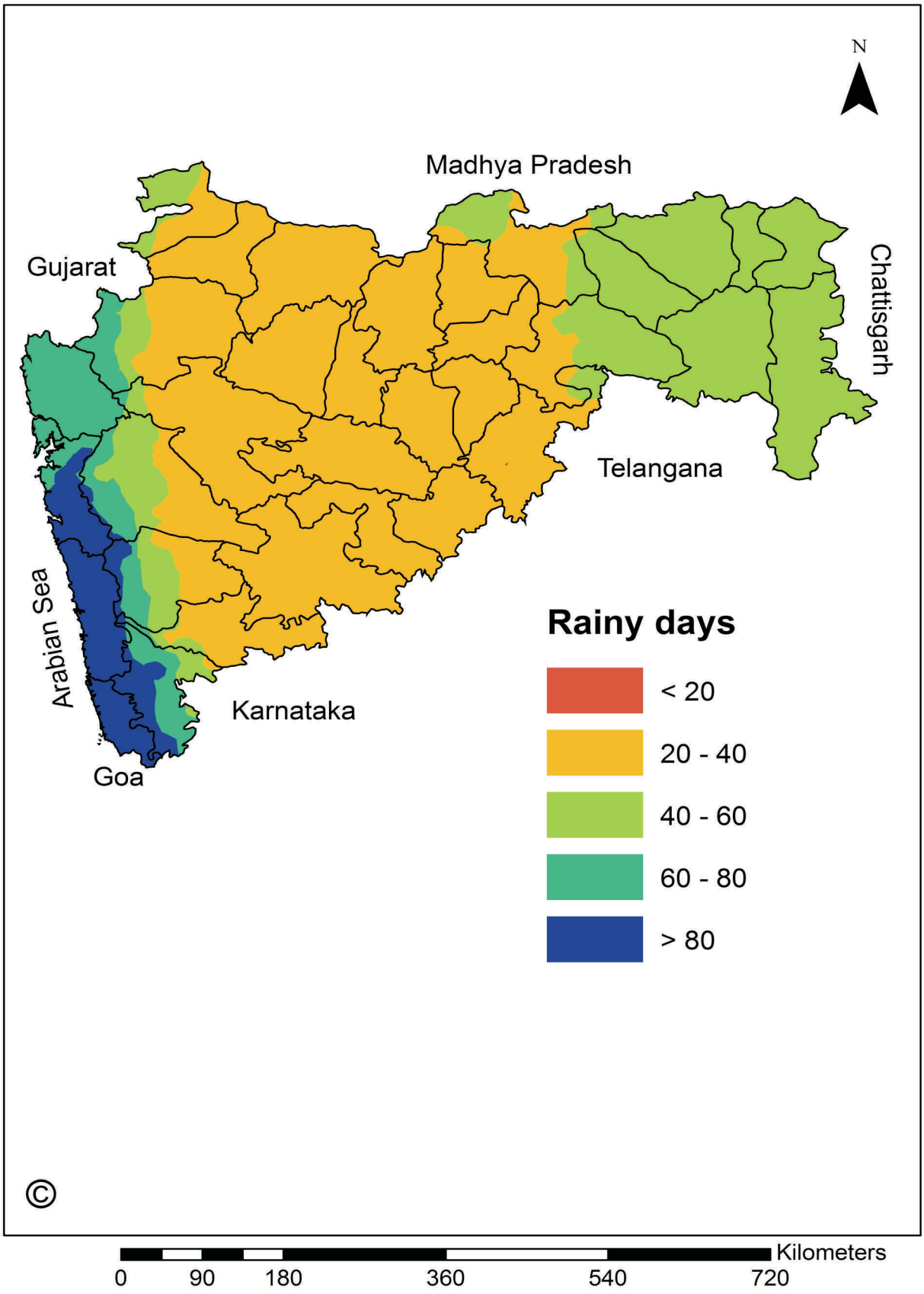


Fig. 56 : Number of rainy days during Southwest monsoon over Maharashtra

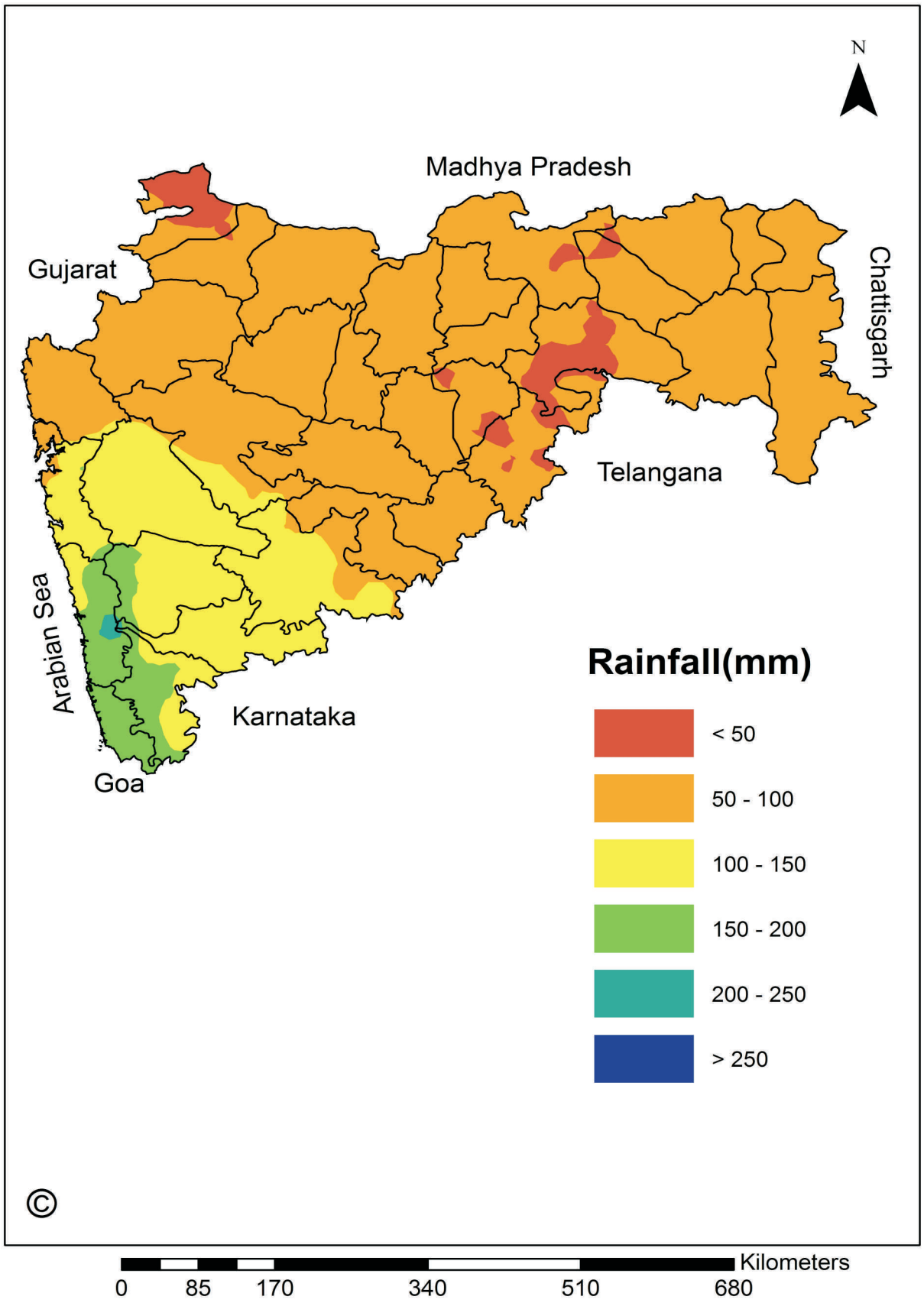


Fig. 57 : Post monsoon rainfall (mm) over Maharashtra

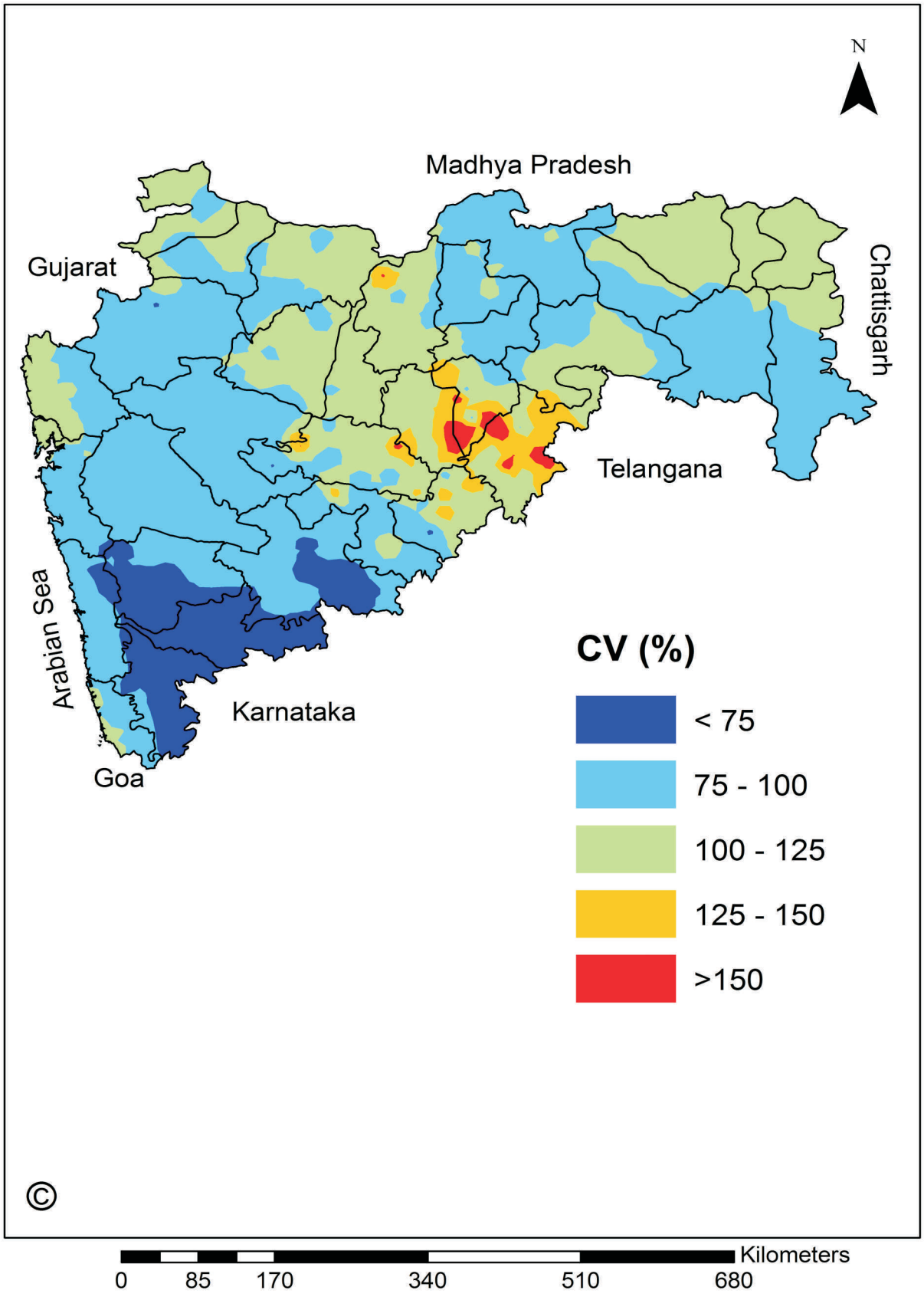


Fig. 58: Variability (CV %) in Post monsoon rainfall (mm) over Maharashtra

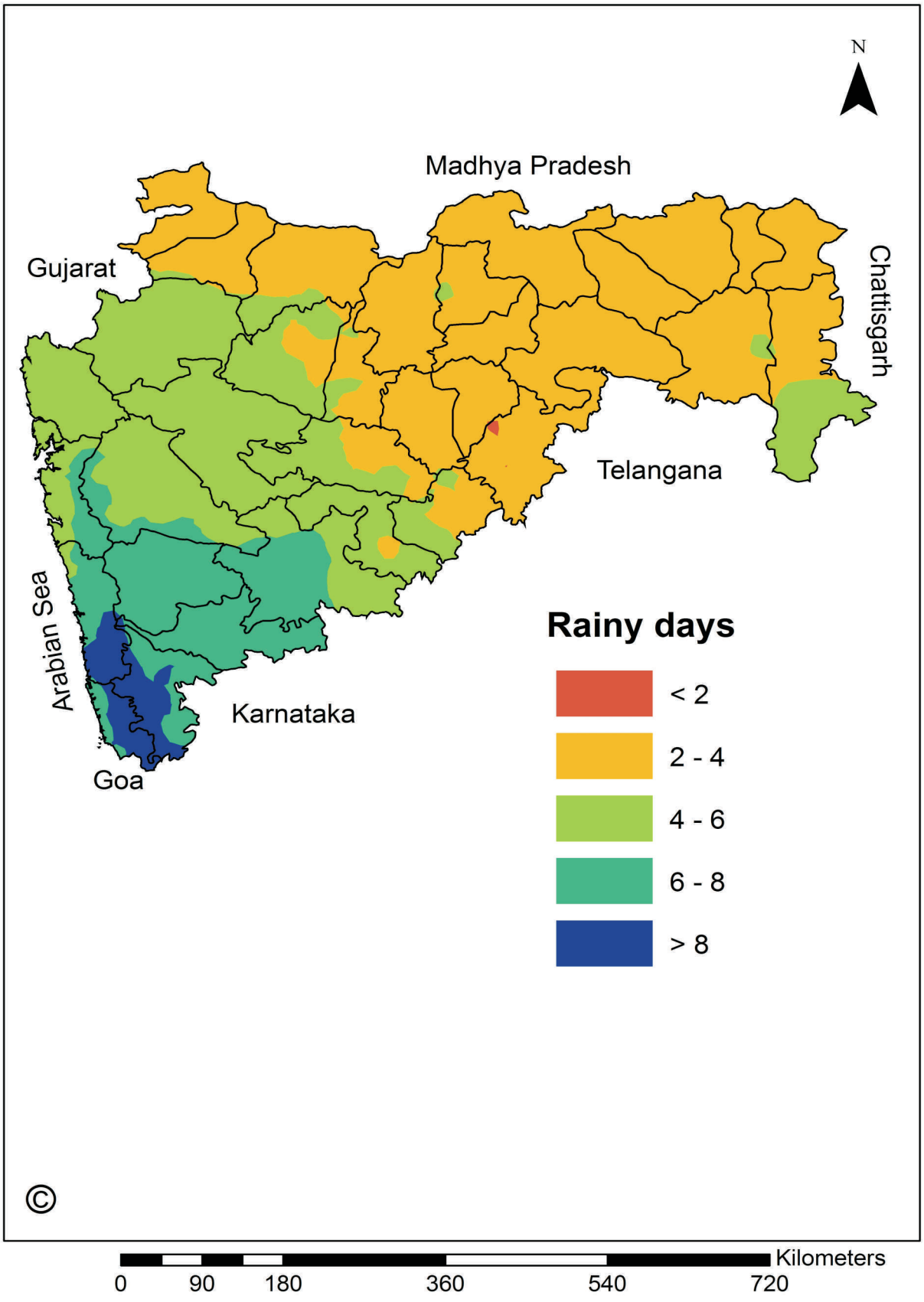


Fig. 59: Number of rainy days during Post monsoon over Maharashtra

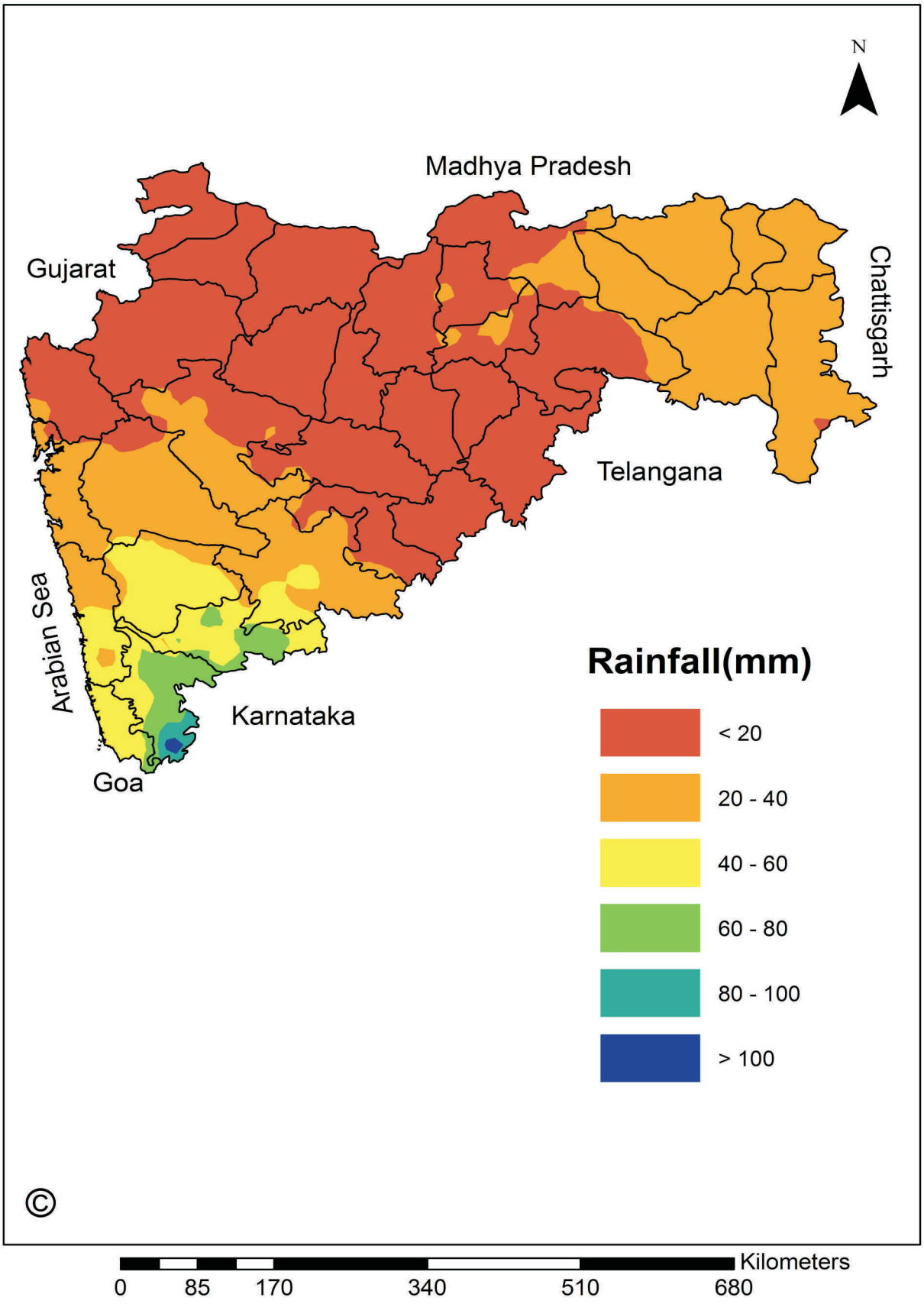


Fig. 60: Summer rainfall (mm) over Maharashtra

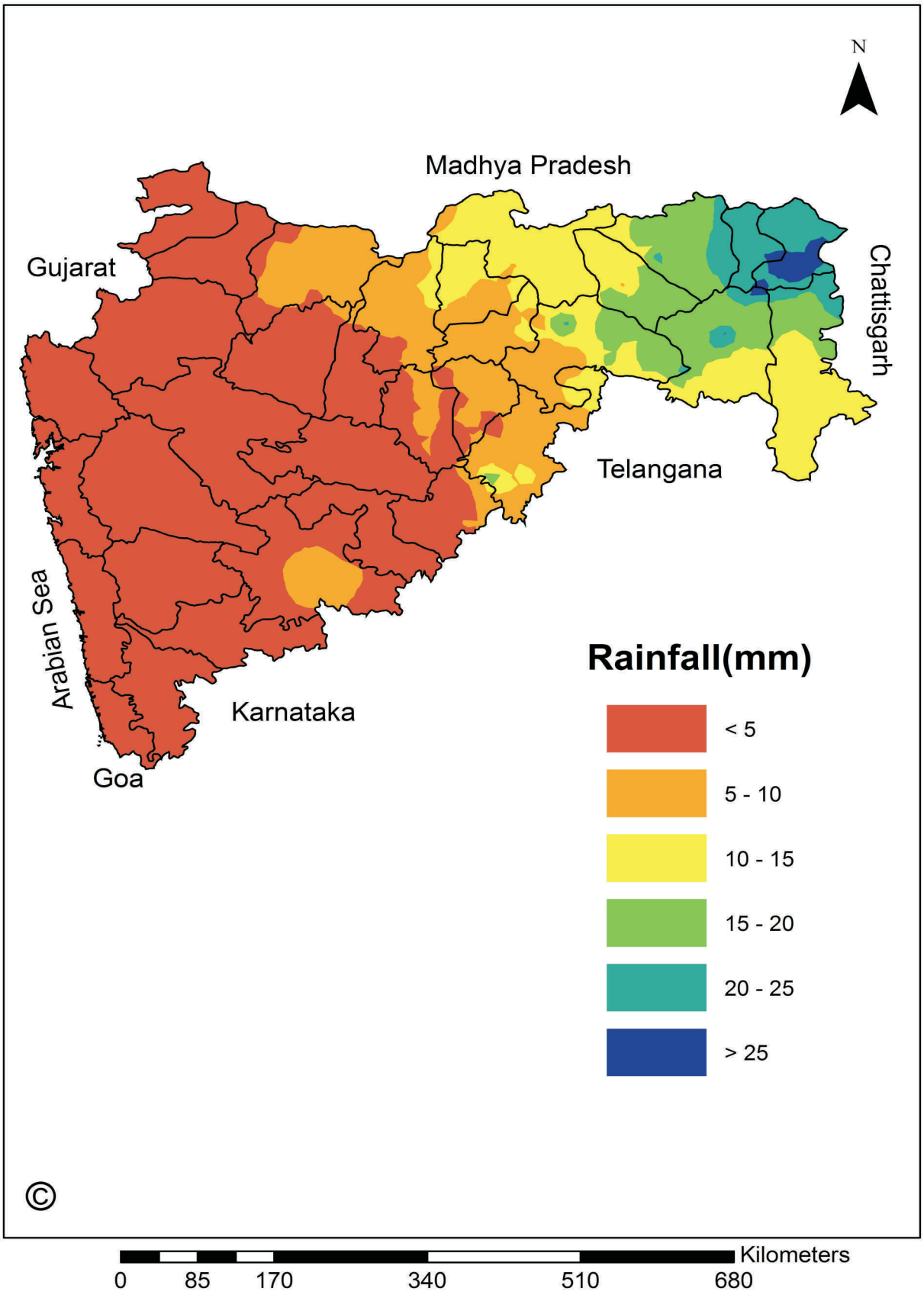


Fig. 61 : Winter rainfall (mm) over Maharashtra

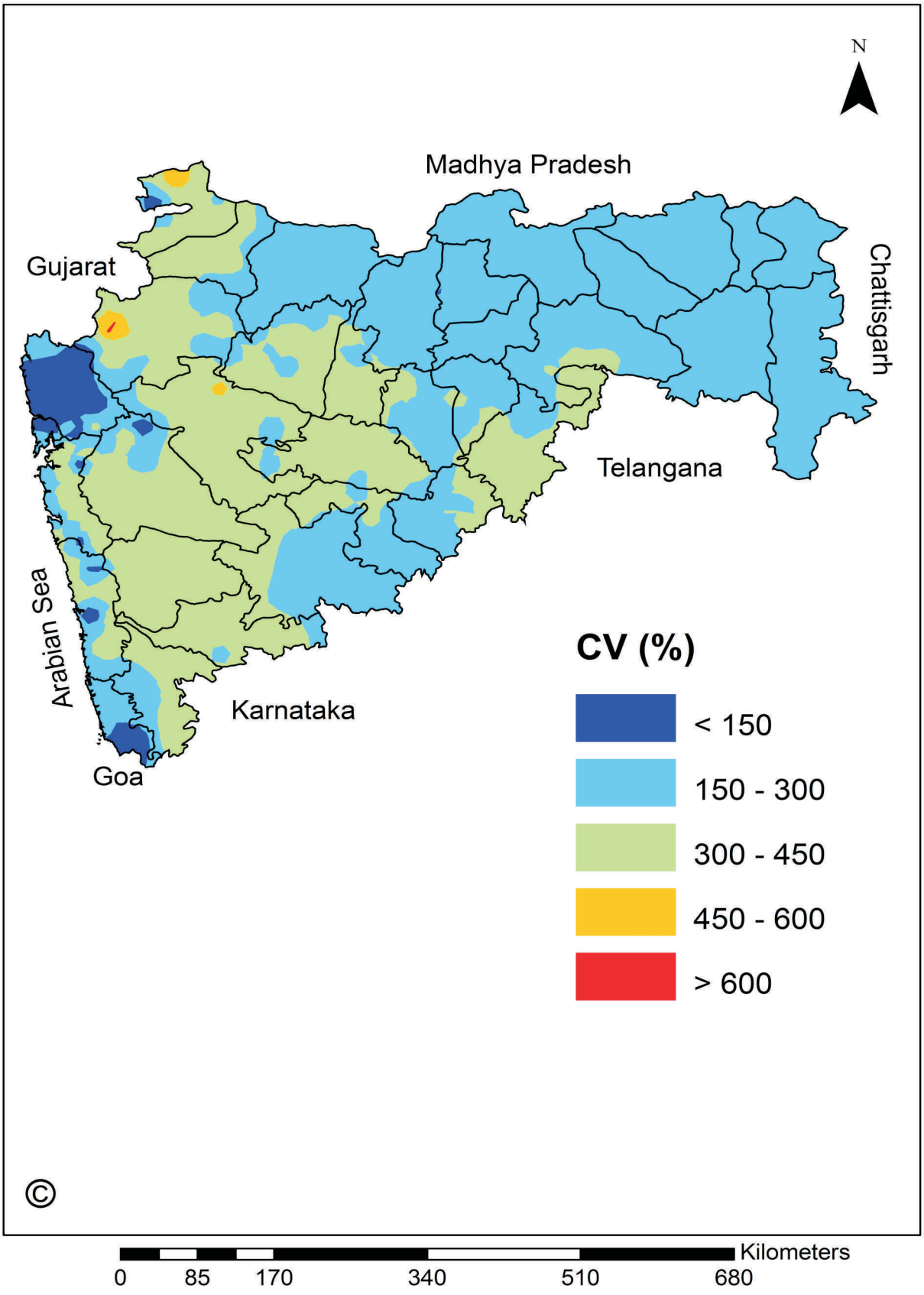


Fig. 62 : Variability (CV %) in winter rainfall (mm) over Maharashtra

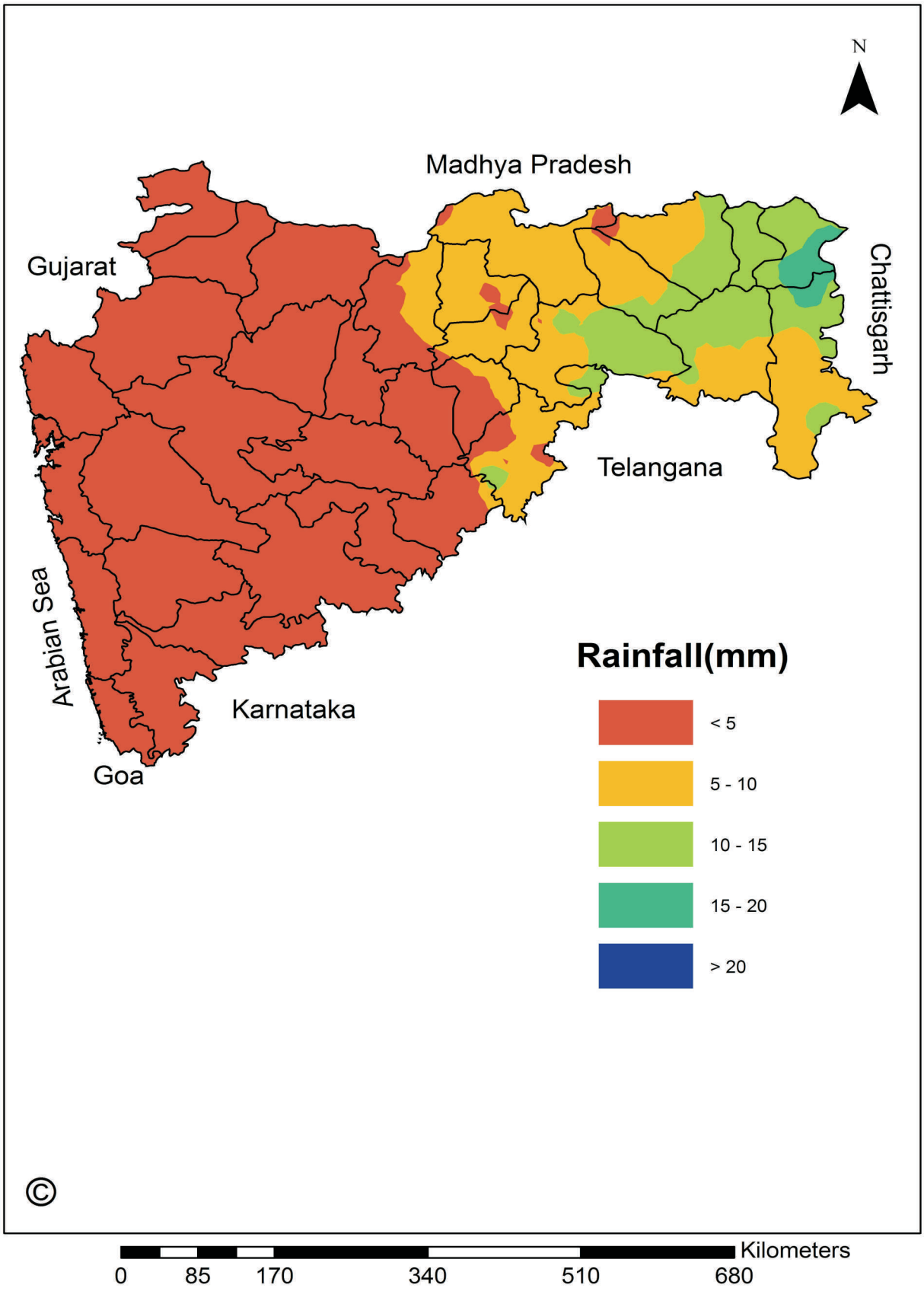


Fig. 63 a: Rain in January in Maharashtra

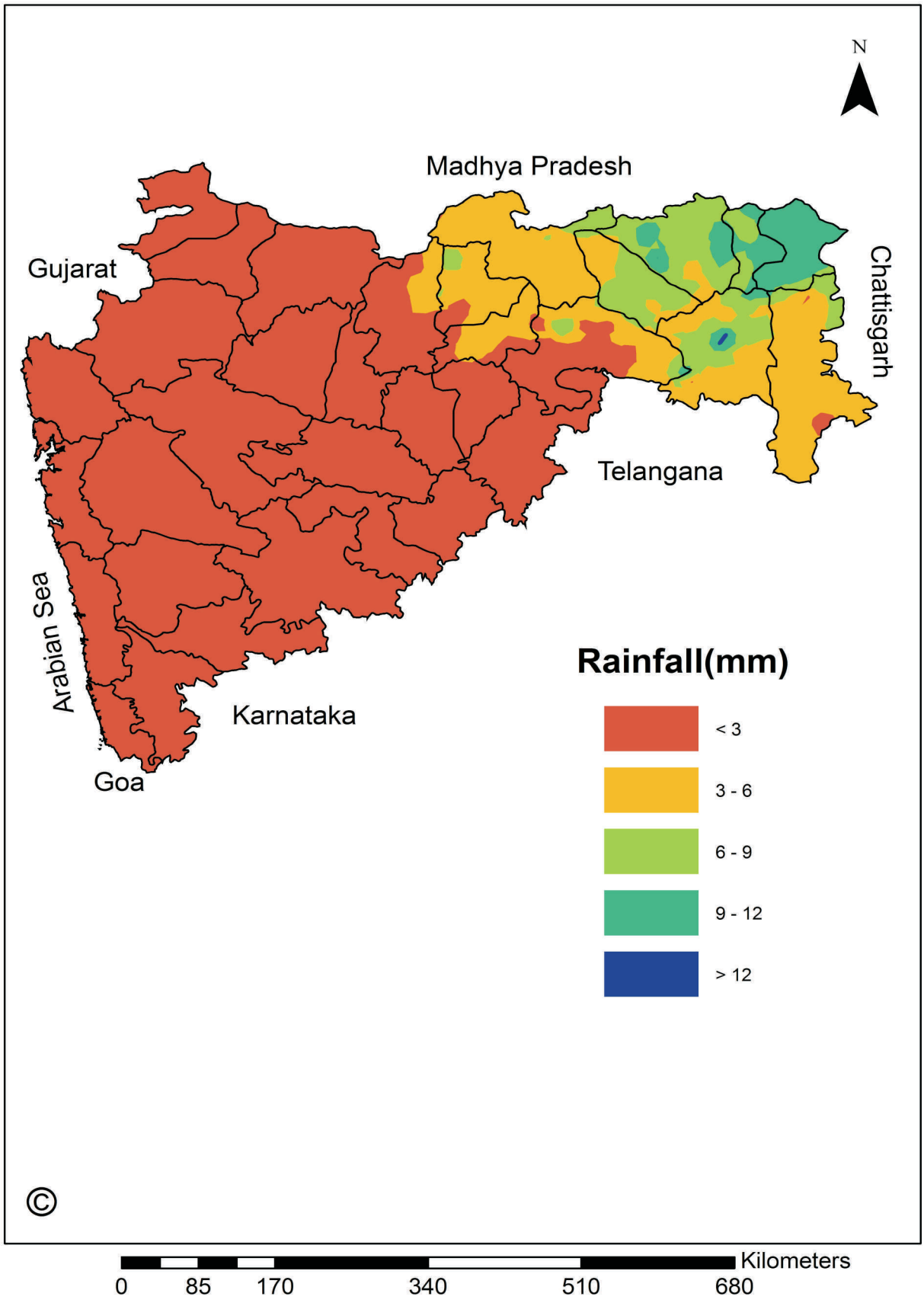


Fig. 63 b: Rain in February in Maharashtra

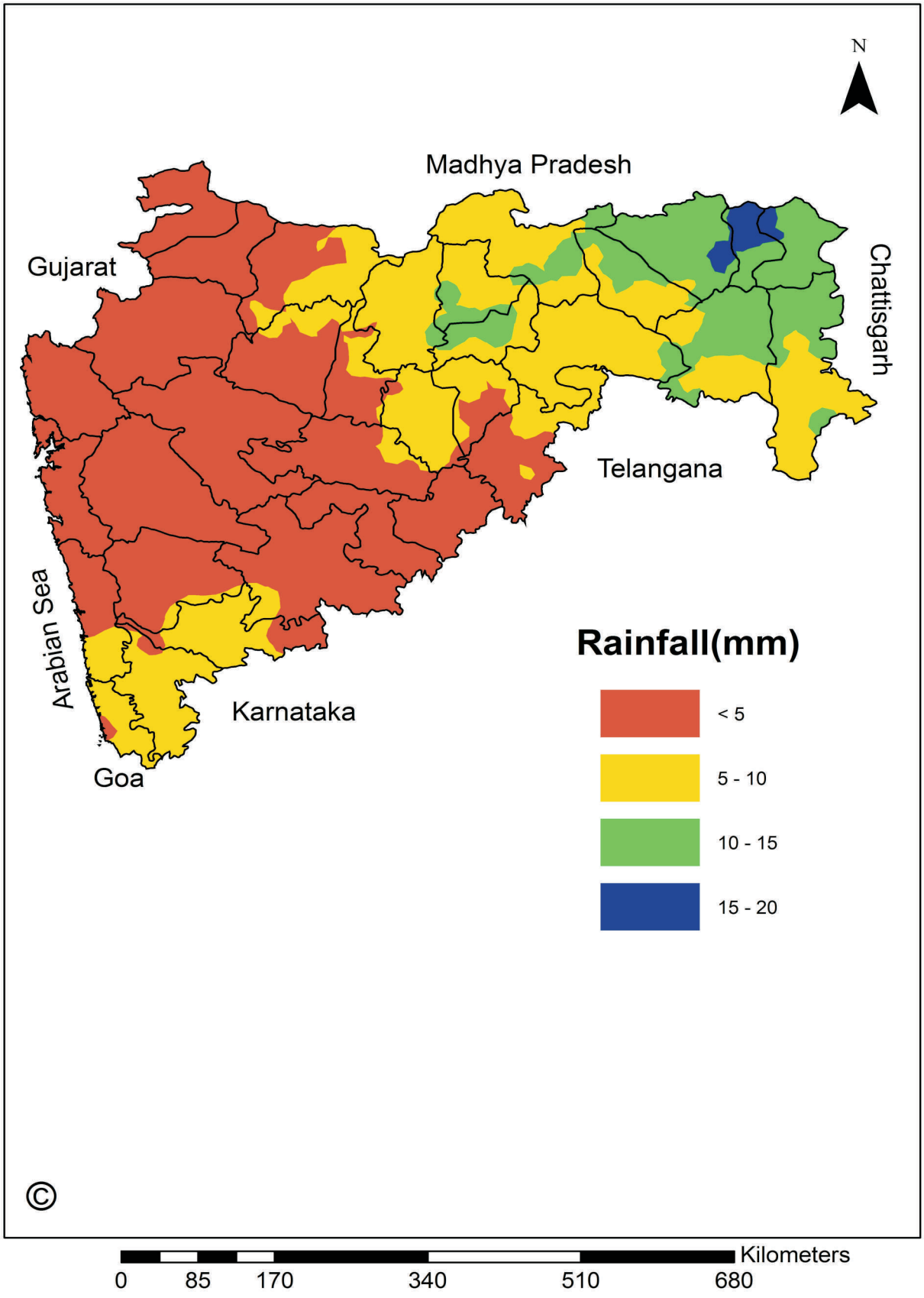


Fig. 63 c: Rain in March in Maharashtra

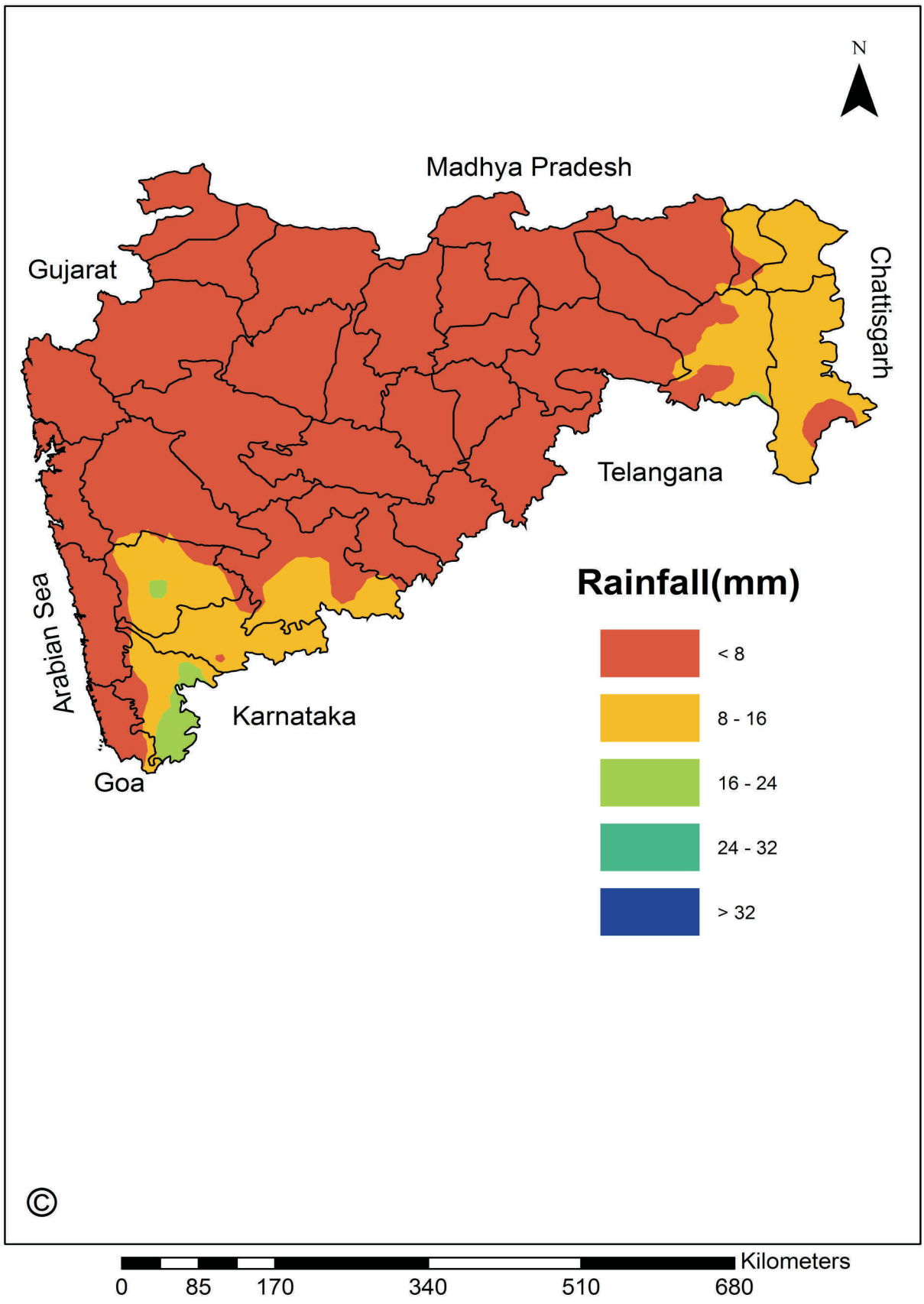


Fig. 63 d: Rain in April in Maharashtra

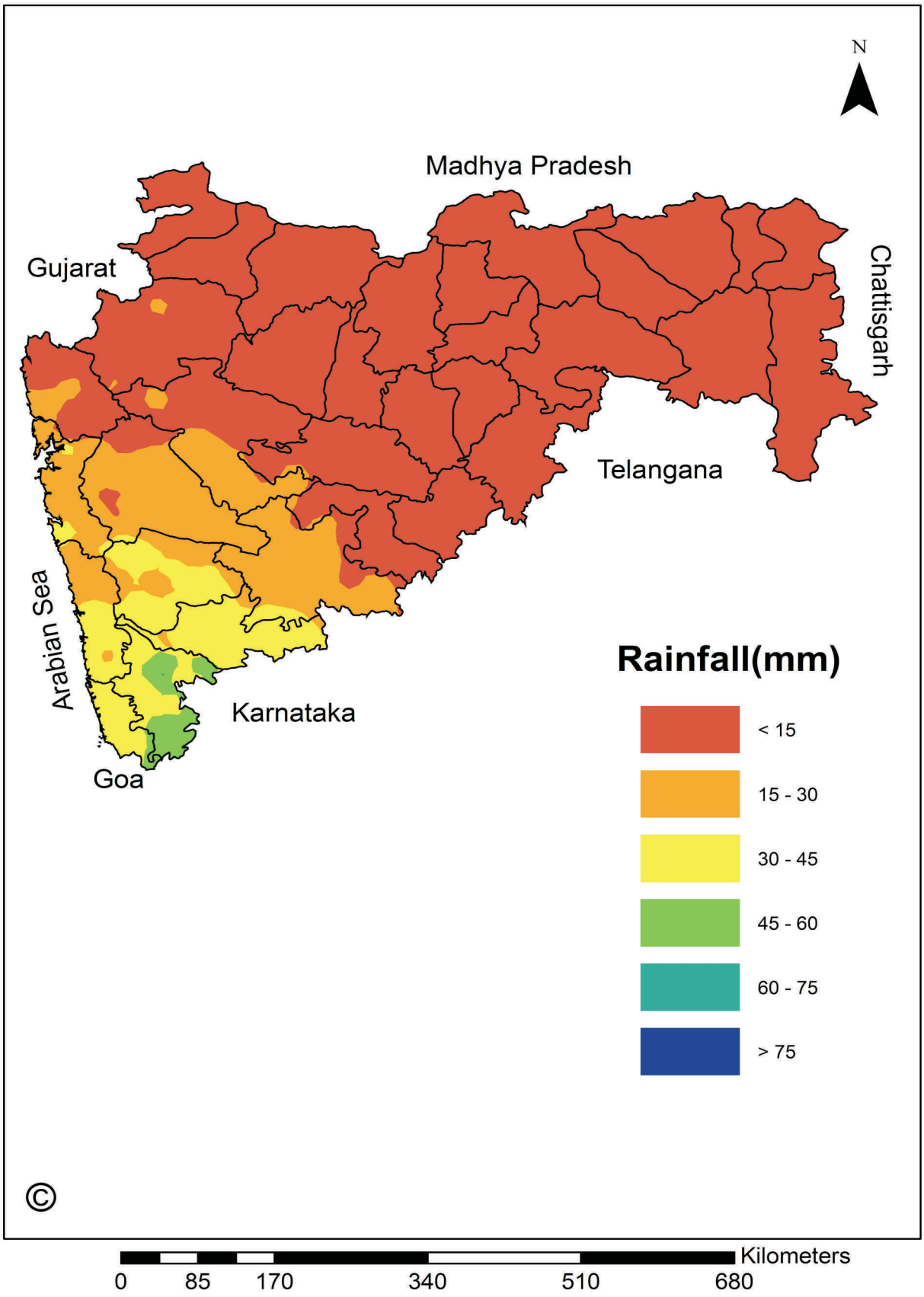


Fig. 63 e: Rain in May in Maharashtra

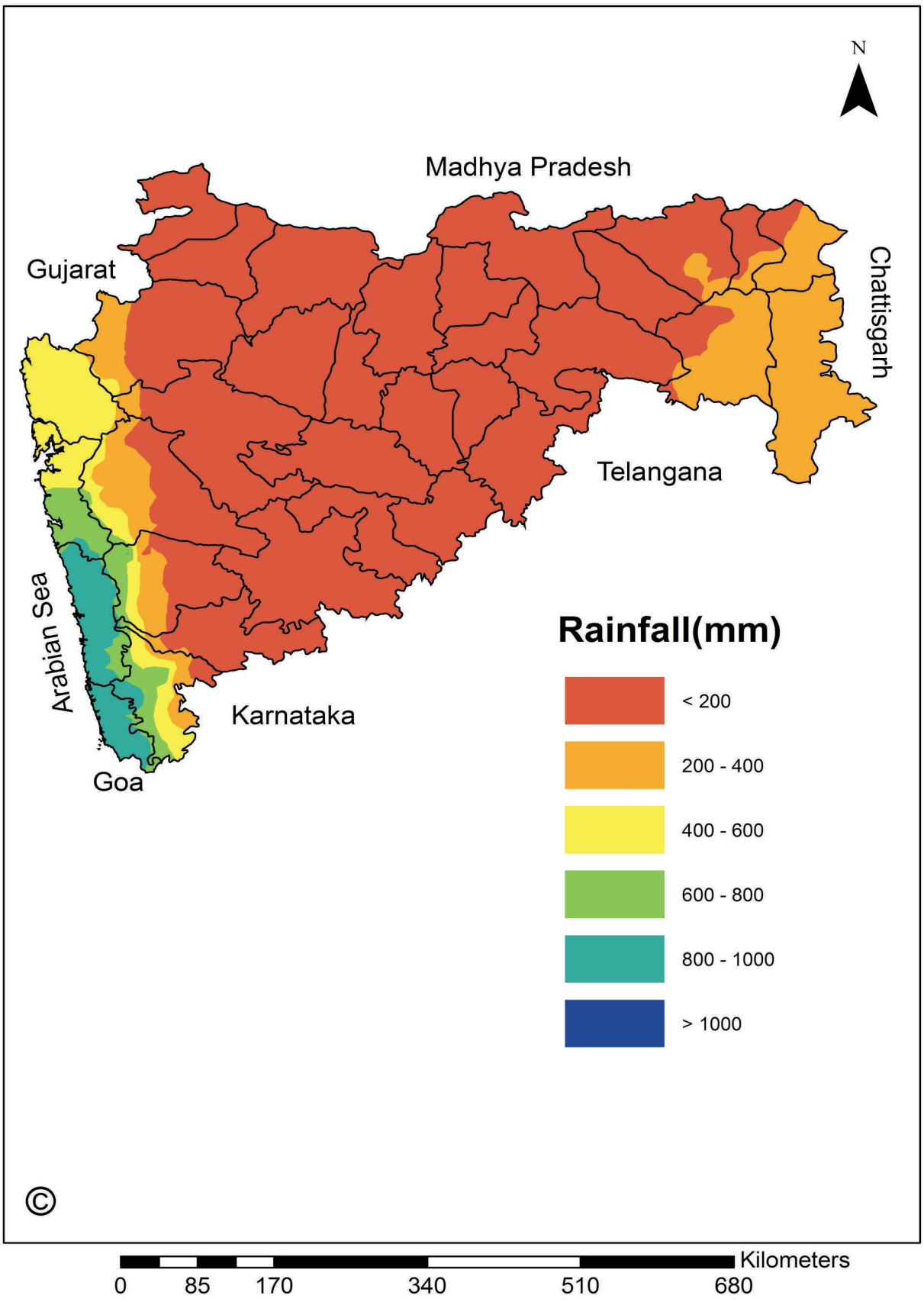


Fig. 63 f: Rain in June in Maharashtra

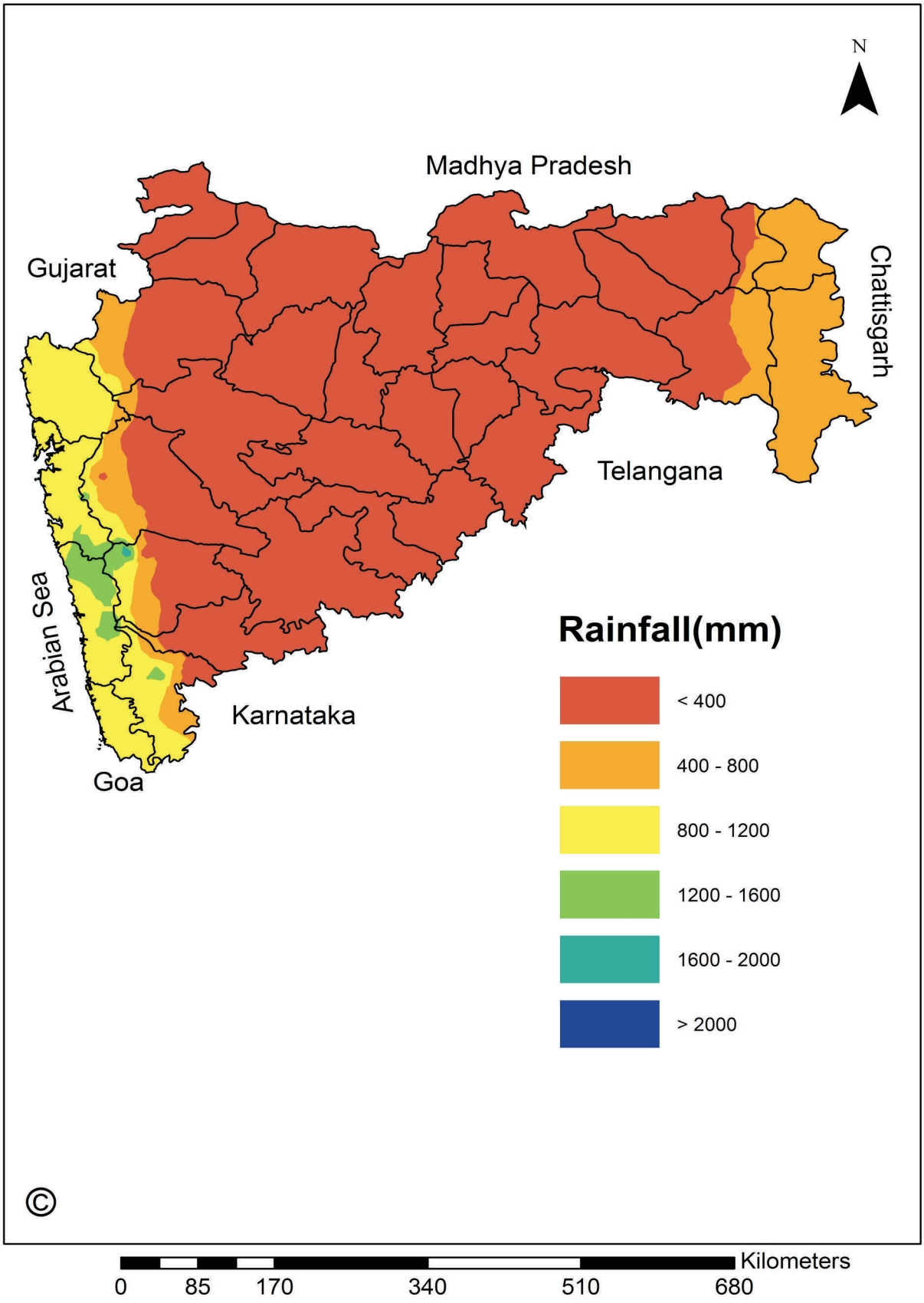


Fig. 63 g: Rain in July in Maharashtra

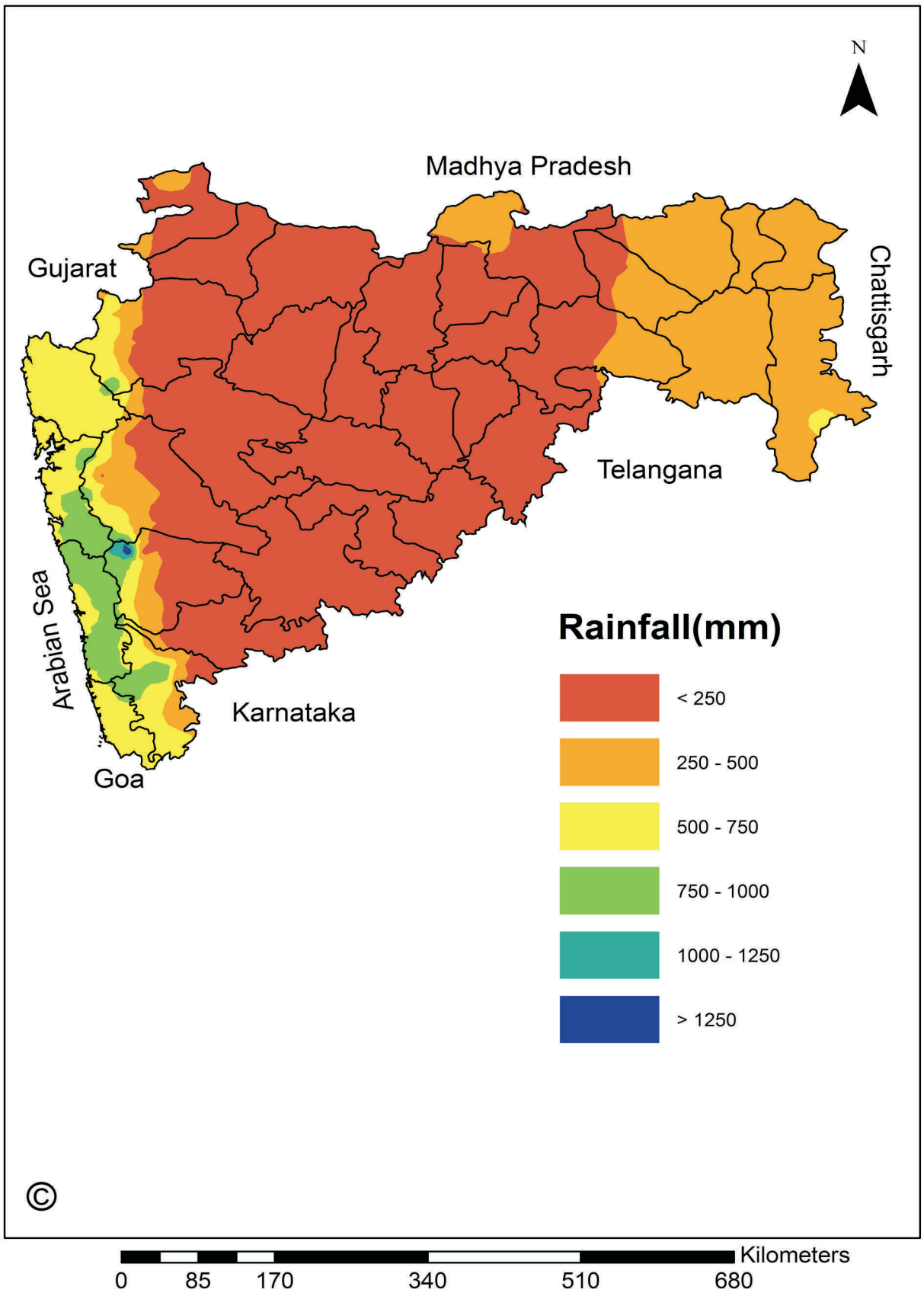


Fig. 63 h: Rain in August in Maharashtra

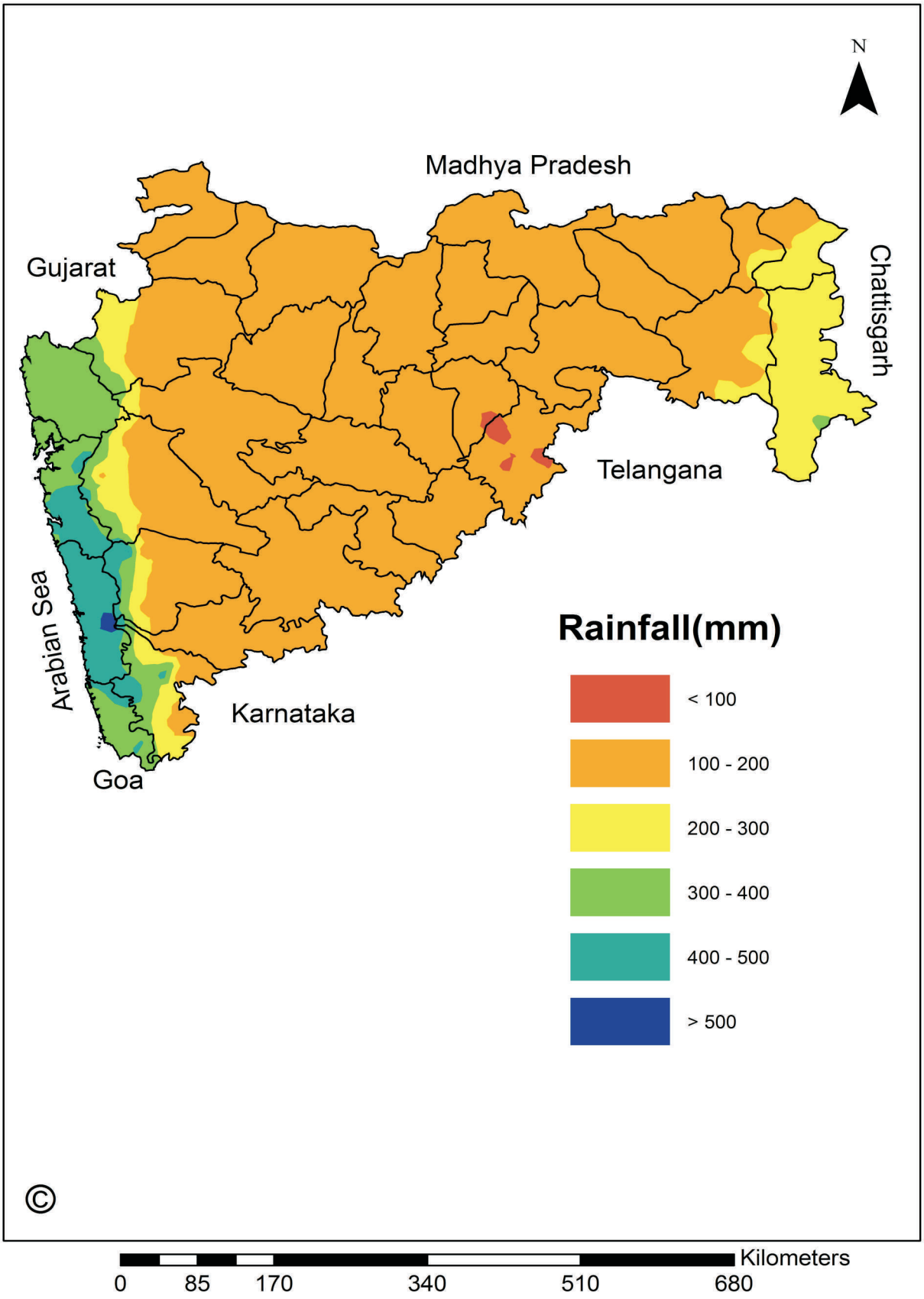


Fig. 63 i: Rain in September in Maharashtra

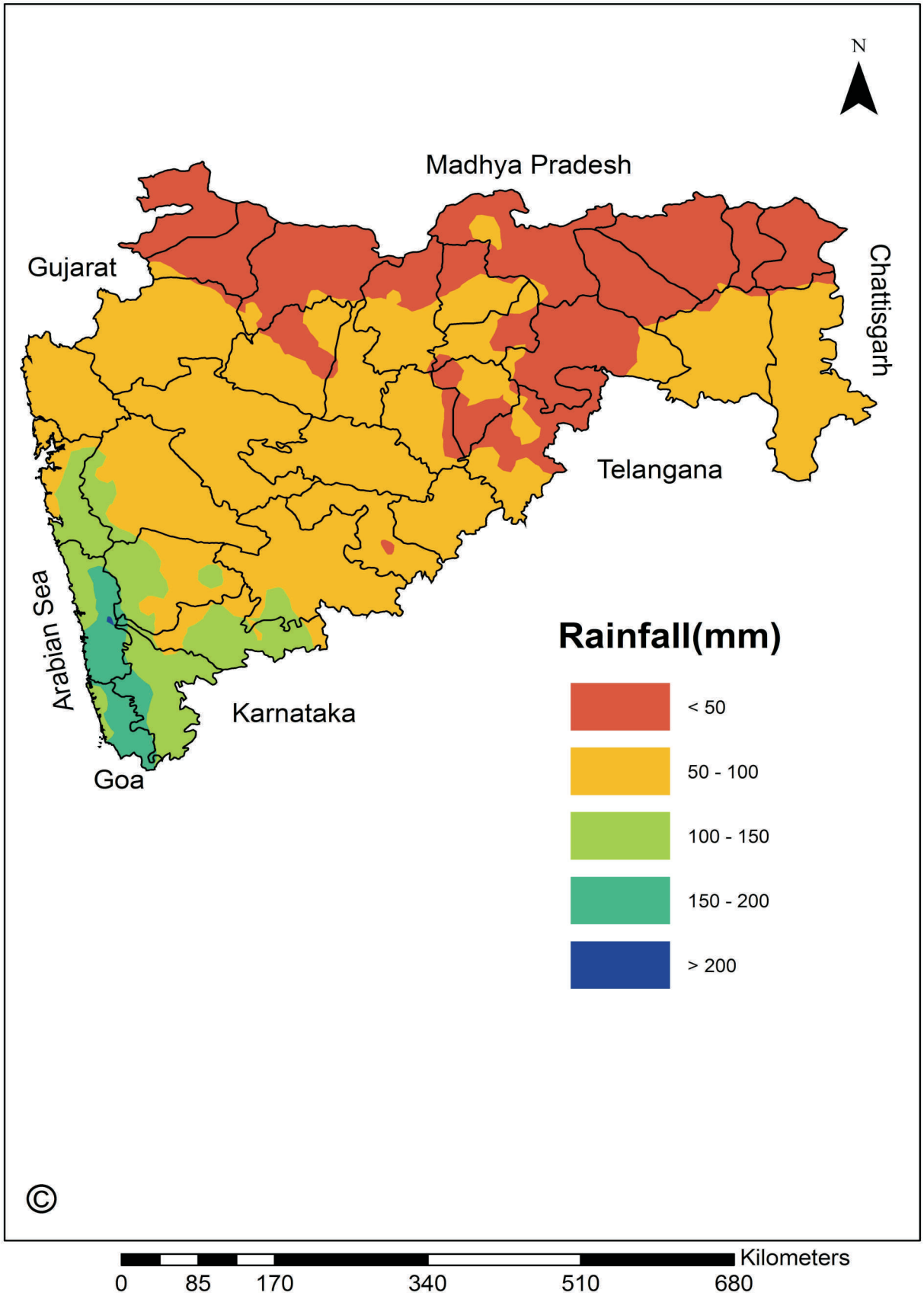


Fig. 63 j: Rain in October in Maharashtra

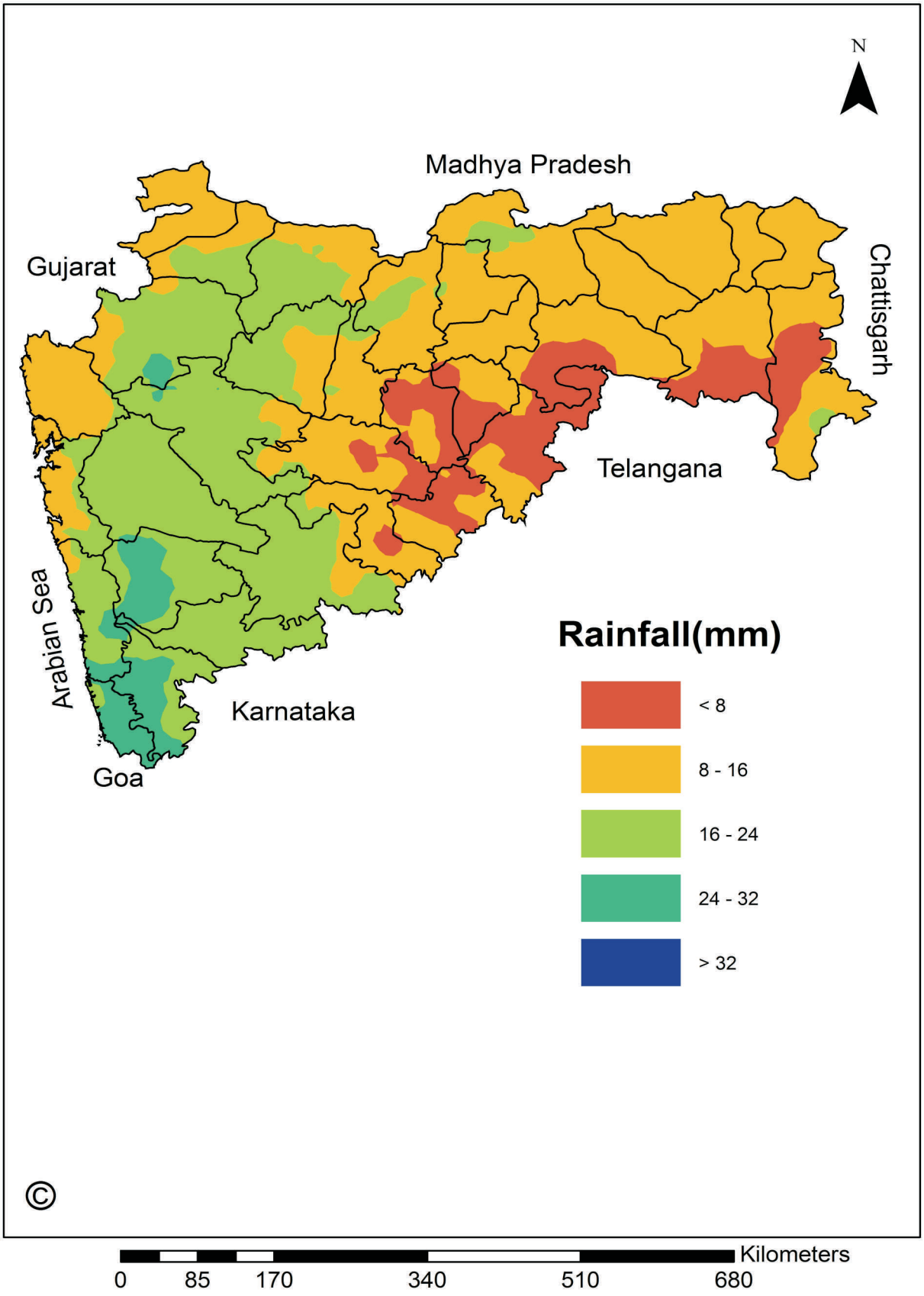


Fig. 63 k: Rain in November in Maharashtra

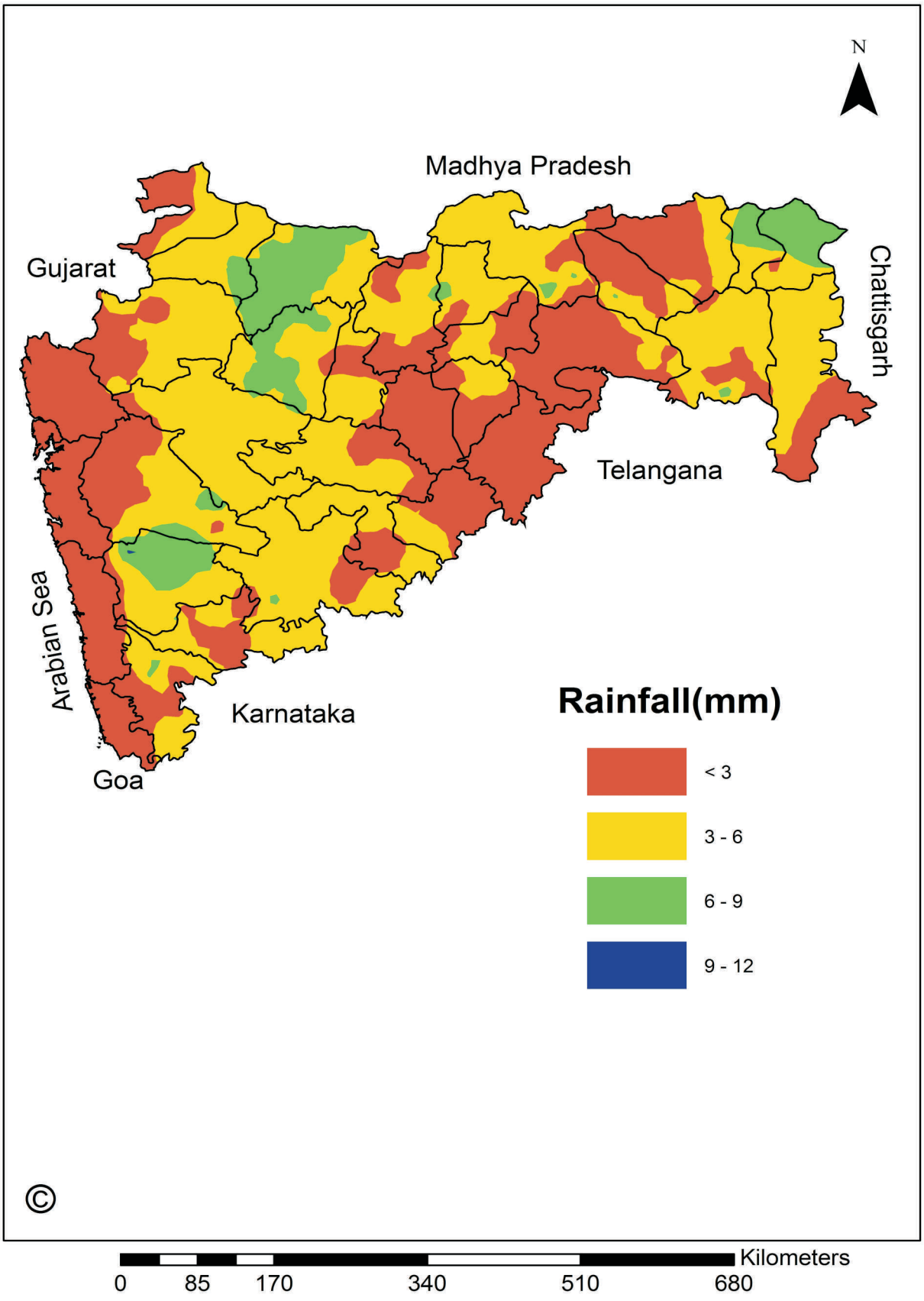


Fig. 63 l: Rain in December in Maharashtra

Table 16: Mean monthly distribution of rainy days in different districts of Maharashtra

District	Jan	Feb	Mar	April	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Ahemadnagar	0	0	0	0	1	6	7	6	7	4	1	0
Jalgaon	0	0	0	0	0	6	11	11	7	2	1	0
Nandurbar	0	0	0	0	0	6	15	14	7	2	1	0
Pune	0	0	0	0	1	8	12	12	9	4	1	0
Satara	0	0	0	1	2	10	14	13	9	5	2	0
Thane	0	0	0	0	2	79	158	116	61	16	1	0
Ratnagiri	0	0	0	0	1	20	28	26	17	6	1	0
Palghar	0	0	0	0	0	14	24	22	13	4	1	0
Beed	0	0	0	0	0	6	7	7	8	3	1	0
Jalana	0	0	0	0	0	6	8	8	7	3	1	0
Nanded	0	0	0	0	0	6	9	8	6	2	0	0
Parbhani	0	0	1	0	0	6	8	8	7	3	1	0
Amravati	0	0	1	0	1	7	13	12	8	2	1	0
Bhandara	1	1	1	1	1	8	16	15	9	3	1	0
Gadchiroli	1	0	1	1	1	9	17	17	9	3	1	0
Nagpur	1	1	1	1	1	8	15	13	9	2	1	0
Washim	0	0	1	0	0	8	12	11	8	3	1	0
State	**0**	**0**	**0**	**0**	**1**	**11**	**18**	**16**	**10**	**4**	**1**	**0**
CV	118	140	87	103	84	116	142	117	90	67	40	94

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 17. Considerable rain (> 20 mm / week) over the state occurs in the period from 22 Standard Meteorological Week (SMW) (2 May -10 June) to 40 SMW (1 - 7 Oct). This indicates a total growing period of 20 weeks (around 140 days).

In majority of the districts, except Latur, Nanded, Akola, Amravati, Bhandara, Buldhana, Chandrapur, Wardha, Yavtamal and Jalgaon, the rainy season commences in the 24th SMW and ends by 40th SMW. In Kolhapur, Pune, Sangli, Satara, Solapur, Raigadh, Ratnagiri and Sindhudurg districts, the rainy season is upto 42 SMW. Isolated rainfall events are noted nearly all districts expect few discticts in the state during 50 to 20 SMW and the rains get momentum with the onset of monsoon from 22 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 *talukas* of Maharashtra.

4.9. Annual rainfall at 75 per cent probability

Highest annual rainfall to the tune of more than 4000 mm is noticed in 2 talukas that are mostly located in the Kolhapur and Satara district, while annual rainfall in the range of 3000- 4000 mm 8 talukas, 2000 – 3000 mm total 38 talukas and 1000 to 2000 mm 41 talukas in different districts of Maharashtra.Hence, it is evident that in these talukas 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 talukas of *Vidharbha* region, talukas of Beed and Hingoli district in the *Marathwada* region and talukas of Kolhapur and Nandurbar districts part of *Madhya Maharashtra* region (Fig. 64). Numerically, 40 talukas receive 800-1000 mm rainfall annually. Cultivation of high value / long or medium duration crops in these talukas 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 353

Taluks in the state which are majorly spread in *Marathwada, Madhya Maharashtra* and *Vidharbha* region, 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 Ahmednagar, Dhule, Jalgaon, Sangali, Satara, Solapur, Aurangabad, Jalana, Latur, Osmanabad, and some talukas of Parbhani, Nanded, Buldhana, Amravati, Karimnagar and Nashik districts. Lowest annual rainfall as expected (at 75 per cent probability) in Ahmednagar district and also in some pockets of Dhule, Solapur, Sangali districts. Rainfed farming and pastoralism are the mainstay in these areas and practicing of crop-based agriculture is a risky proposition. Crop failures are common here due to a large inter-annual as well as intra-seasonal variation of rain.

It is evident from the above that around 59% of the geographical area of the state of 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 rainfall 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.

Table 17: Mean weekly rainfall in different districts of Maharashtra

week	Aurangabad	Beed	Hingoli	Jalana	Latur	Nanded	Osmanabad	Parbhani	Akola	Amravati	Bhandara	Buldhana	Chandrapur	Gadchiroli	Gondia	Nagpur	Wardha	Washim	Yavatmal	A.nagar	Dhule	Jalgaon	Kolhapur	Nandurbar	Nashik	Pune	Sangli	Satara	Solapur	Thane	Raigadh	Ratnagiri	Sindhudurg	Palghar	state	sd	cv
1	0.3	0.3	1.1	0.4	0.4	0.8	0.3	1.1	2.1	2.9	1.4	2.2	1.1	1.6	2.0	1.0	1.9	2.1	1.0	0.3	0.1	0.9	0.3	0.1	0.5	0.3	0.1	0.4	0.3	0.2	0.2	0.2	0.8	0.0	0.8	0.8	92
2	0.3	0.2	1.4	0.0	0.7	1.4	0.8	0.7	2.3	1.9	3.6	0.7	2.4	2.8	3.5	0.6	1.1	1.5	2.1	0.2	0.5	0.9	0.1	0.2	0.2	0.0	0.4	0.1	1.0	0.1	0.0	0.0	0.0	0.0	0.9	1.0	110
3	0.3	0.0	0.4	0.3	0.1	2.9	0.0	0.9	0.3	0.4	1.1	0.2	0.7	0.5	1.1	0.3	0.6	0.1	0.6	0.4	0.2	0.5	0.3	0.1	0.0	0.1	0.4	0.2	1.4	0.0	0.0	0.0	0.0	0.0	0.4	0.6	132
4	0.3	0.0	0.4	0.0	0.0	0.5	0.0	0.4	0.7	0.9	2.3	0.3	1.5	1.7	2.5	2.2	0.8	0.3	1.7	0.0	0.4	0.2	0.0	0.2	0.1	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.7	142
5	0.7	0.1	0.0	0.2	0.6	0.8	0.0	0.4	1.7	1.5	6.0	1.1	4.3	4.2	7.1	7.4	3.9	1.7	4.4	0.3	0.4	0.4	0.0	0.1	0.2	0.0	0.4	0.2	0.3	0.0	0.2	0.0	0.0	0.0	1.4	2.2	151
6	0.1	0.1	0.4	0.1	0.3	0.2	0.0	0.4	1.4	2.1	3.0	0.9	1.5	1.1	3.6	2.2	2.2	2.7	1.0	0.0	0.2	0.5	0.1	0.0	0.4	0.0	0.0	0.0	0.6	0.0	0.0	0.2	0.0	0.0	0.7	1.0	134
7	0.1	0.2	0.0	0.0	0.4	0.9	0.2	0.0	0.2	0.7	3.0	0.2	2.1	0.9	3.2	0.7	1.0	0.3	0.7	0.0	0.2	0.8	0.5	0.0	0.1	0.1	0.1	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.5	0.8	149
8	0.1	0.1	0.5	0.0	0.1	0.3	0.0	0.2	1.7	1.2	1.0	0.4	1.0	0.8	1.7	1.0	2.0	0.5	0.5	0.4	0.4	1.3	0.2	0.0	0.3	0.0	0.0	0.2	0.4	0.0	0.1	0.0	0.0	0.1	0.5	0.6	114
9	1.3	1.6	2.3	0.8	1.9	1.2	1.7	2.5	2.1	3.3	4.5	1.6	3.7	2.8	4.6	3.6	3.4	3.7	1.7	0.6	0.6	0.5	0.4	0.1	0.2	0.1	0.1	0.2	0.6	1.0	2.1	1.5	1.7	0.2	1.7	1.3	78
10	2.1	1.5	2.7	1.2	1.3	1.5	1.1	3.7	3.4	2.2	3.6	3.1	2.4	3.3	3.6	4.0	3.3	4.5	2.3	0.2	0.1	0.6	0.7	0.0	0.1	0.1	0.1	0.3	0.4	0.4	0.2	0.0	1.0	0.8	1.6	1.4	86
11	1.4	0.4	0.4	1.2	0.8	1.7	0.2	0.9	2.4	2.4	4.8	1.9	1.9	1.7	4.1	4.5	1.9	2.6	1.5	0.7	1.0	2.0	1.5	0.4	0.5	1.1	1.3	0.7	0.8	0.0	0.0	0.0	0.0	0.0	1.4	1.2	90
12	0.2	0.5	0.2	0.3	0.3	0.3	0.5	0.7	0.4	0.3	1.6	0.1	1.9	1.4	1.5	0.4	0.7	1.9	0.2	1.3	0.7	0.9	3.2	0.4	0.3	1.3	3.8	1.4	1.1	0.0	0.1	1.7	2.5	0.0	0.9	0.9	97
13	0.0	0.0	0.1	0.0	0.0	0.2	0.7	0.1	0.9	0.4	2.1	0.4	1.0	1.0	2.3	0.3	0.5	0.2	0.5	0.5	1.5	0.8	1.3	0.2	0.2	0.3	0.9	1.4	1.0	0.0	0.0	0.9	1.6	0.0	0.6	0.6	99
14	0.2	0.2	0.1	0.1	0.3	0.3	1.0	0.1	0.4	0.2	1.6	0.2	1.9	1.9	1.8	0.7	1.1	1.0	0.5	0.7	0.3	0.2	2.7	0.1	0.5	0.9	1.3	2.1	2.0	0.0	0.0	0.0	0.0	0.0	0.7	0.8	106
15	0.6	1.3	1.1	0.8	1.5	1.4	1.8	1.1	1.0	0.4	2.3	1.3	1.0	1.2	2.9	3.2	1.2	2.1	0.5	1.3	0.4	0.3	4.5	0.3	0.3	2.2	2.5	2.7	3.0	0.1	0.0	0.0	1.2	0.0	1.3	1.1	81
16	0.0	0.1	0.2	0.2	0.2	0.4	0.7	0.5	0.1	0.4	2.4	0.1	2.7	4.7	5.5	0.4	1.2	0.8	1.0	0.5	0.1	0.2	6.1	0.1	0.2	0.4	2.1	2.6	1.3	0.0	3.2	0.2	0.7	0.0	1.1	1.6	141
17	0.0	0.0	0.2	0.2	0.1	0.1	0.2	0.1	0.3	0.1	1.3	0.2	1.1	3.7	0.8	1.2	0.4	0.1	0.4	0.5	0.4	0.1	5.8	0.3	0.5	0.7	2.8	4.3	1.6	0.0	0.0	0.0	0.0	0.0	0.8	1.3	168
18	0.3	0.7	0.3	0.2	0.4	1.2	1.6	0.4	0.3	0.4	2.4	0.1	2.0	2.8	2.1	1.6	2.4	0.4	0.5	4.3	0.4	0.4	6.5	0.8	1.7	2.4	6.1	5.6	3.0	0.1	0.3	0.4	0.4	0.0	1.5	1.8	115
19	0.3	0.4	0.8	0.3	0.3	1.1	1.0	0.3	0.6	0.7	1.9	0.2	2.4	1.7	2.8	0.7	2.9	0.8	0.8	1.1	1.3	2.3	5.7	1.1	3.1	1.9	3.8	4.2	3.0	0.1	1.2	0.3	1.7	0.5	1.5	1.3	88
20	1.1	2.0	0.7	1.4	0.5	0.5	1.5	2.7	0.7	0.6	1.8	0.7	2.1	2.6	1.7	2.4	2.2	1.3	1.1	2.6	1.4	0.9	10.7	0.5	1.6	4.2	8.0	7.1	5.2	5.8	12.4	5.6	1.1	7.8	3.0	3.1	101
21	0.4	2.6	0.5	0.3	0.6	1.1	2.0	1.1	1.1	3.7	2.8	0.9	1.9	2.5	2.7	2.2	3.9	1.2	1.3	5.3	1.8	1.4	13.1	1.1	2.0	3.2	12.9	8.4	6.6	0.5	5.5	6.9	9.3	0.9	3.3	3.4	102
22	5.2	7.0	11.3	3.7	3.4	2.2	8.3	2.9	5.2	2.7	3.1	3.6	3.6	5.9	2.1	2.4	5.0	2.4	2.4	8.2	6.5	4.2	31.8	4.6	9.1	13.2	18.2	20.8	12.0	15.7	31.0	47.7	55.6	17.9	11.2	12.9	115
23	25.2	25.5	26.5	21.7	18.8	15.7	24.4	18.2	18.2	17.9	15.5	17.6	18.1	22.6	15.3	11.9	15.3	20.0	15.4	25.2	20.7	19.1	48.7	22.2	28.8	32.0	27.5	42.3	26.2	48.6	78.9	112.9	137.1	46.0	31.8	27.3	86
24	32.4	29.5	38.6	31.3	25.6	30.4	29.7	33.0	44.6	41.7	53.3	39.0	51.0	64.9	51.0	41.6	44.8	54.1	43.3	26.8	29.8	31.4	87.0	36.3	40.2	43.5	25.3	55.5	26.2	115.9	159.3	231.7	242.0	122.0	60.4	53.8	89
25	24.9	24.0	38.6	24.6	25.3	24.8	18.0	23.7	38.6	41.9	57.5	31.1	50.9	68.8	67.4	51.8	50.6	39.0	44.6	22.5	30.6	29.6	103.8	35.7	45.1	47.6	27.1	65.8	19.9	136.9	189.7	271.5	252.8	129.6	63.4	62.8	99
26	28.5	26.3	44.6	28.7	21.2	37.7	21.4	34.4	45.6	52.1	75.4	44.0	83.8	89.8	82.0	82.3	68.7	60.1	67.1	24.6	38.0	41.7	128.8	59.5	58.5	58.7	21.6	82.1	19.0	196.9	251.0	282.7	248.8	219.7	80.1	72.5	90
27	29.3	26.3	41.3	30.0	29.2	28.6	28.6	31.9	44.0	57.7	63.0	44.8	71.3	82.7	65.7	61.2	58.0	49.5	57.2	25.0	39.3	42.9	140.1	63.5	72.6	54.7	23.4	91.4	22.0	205.1	257.8	281.6	265.4	224.2	79.7	75.1	94
28	27.7	27.3	41.0	28.1	32.1	45.5	22.2	35.4	44.8	53.7	84.4	37.1	87.4	116.5	97.2	67.9	63.0	47.1	59.9	19.3	40.0	36.8	131.9	63.3	61.0	44.3	20.1	88.3	18.2	207.4	228.7	244.2	223.1	197.4	77.7	66.2	85
29	29.5	24.2	50.4	29.8	29.9	36.4	26.3	33.4	50.4	56.1	98.5	44.5	83.2	115.1	111.3	84.9	68.1	62.1	58.6	19.4	33.0	40.3	151.7	61.6	68.1	48.6	25.5	105.6	18.8	178.8	227.3	270.9	233.2	186.8	81.2	67.2	83
30	37.8	32.6	42.5	38.9	38.5	50.2	33.1	46.9	59.9	65.6	94.3	54.5	94.8	106.7	117.7	83.8	77.4	60.2	68.6	24.4	44.9	48.5	165.0	79.5	85.6	69.8	31.4	108.9	28.9	252.6	260.8	301.5	265.2	223.3	93.9	77.0	82
31	27.4	21.5	56.3	30.0	37.6	44.9	26.6	38.3	54.2	71.0	96.9	52.3	85.5	115.2	101.2	82.3	72.3	61.3	69.0	19.3	36.5	46.0	145.7	69.2	76.7	69.5	26.3	104.3	22.7	250.4	271.4	280.5	216.8	269.7	89.7	77.1	86

week	Aurangabad	Beed	Hingoli	Jalana	Latur	Nanded	Osmanabad	Parbhani	Akola	Amravati	Bhandara	Buldhana	Chandrapur	Gadchiroli	Gondia	Nagpur	Wardha	Washim	Yavatmal	A.nagar	Dhule	Jalgaon	Kolhapur	Nandurbar	Nashik	Pune	Sangli	Satara	Solapur	Thane	Raigadh	Ratnagiri	Sindhudurg	Palghar	state	sd	cv
32	40.2	30.9	46.9	36.4	32.7	45.7	25.3	44.1	62.5	66.1	84.2	54.5	78.3	106.2	84.7	68.5	68.9	68.5	62.1	20.6	34.8	53.8	143.2	70.5	82.3	61.2	25.1	92.5	20.5	226.2	235.3	244.3	187.1	234.4	83.5	65.6	79
33	21.1	20.5	32.8	18.4	22.6	27.8	21.8	22.5	31.7	41.5	84.5	26.6	77.6	99.2	92.4	48.9	39.9	22.1	32.8	15.1	24.4	32.4	94.9	43.9	56.2	34.3	14.6	71.6	18.8	100.9	109.2	122.2	125.7	91.4	51.2	34.8	68
34	35.1	38.7	40.4	33.1	43.2	37.5	34.9	40.7	44.4	47.1	75.8	42.9	70.5	86.4	83.9	48.3	47.8	49.7	48.1	29.1	27.5	38.5	65.1	45.1	49.9	29.2	25.0	51.4	34.3	84.0	100.1	117.7	115.0	91.5	54.5	25.3	46
35	34.2	36.0	36.8	36.8	33.8	35.5	31.6	37.8	43.5	47.2	66.5	47.1	64.2	86.1	79.4	57.2	49.0	46.0	43.7	24.9	29.9	40.6	67.8	46.6	48.9	38.4	21.8	56.1	29.7	135.7	167.7	195.0	152.3	119.1	61.4	42.8	70
36	31.9	32.9	30.7	27.8	34.9	30.7	34.6	36.0	37.9	51.3	64.3	37.8	63.9	80.9	65.0	57.1	52.5	40.3	41.2	27.2	29.3	40.9	55.9	49.7	51.4	40.1	23.4	44.9	32.8	108.5	111.9	131.7	109.9	104.7	53.4	28.6	54
37	34.4	39.5	30.3	28.5	38.6	26.8	43.3	29.5	21.3	28.4	49.2	26.4	41.6	49.4	57.4	53.8	32.2	33.8	29.7	35.6	23.2	26.4	40.7	28.6	44.5	41.0	26.5	37.2	38.7	88.5	97.2	102.4	87.3	90.3	44.2	22.4	51
38	36.9	36.9	31.2	29.5	32.5	28.3	40.2	33.5	24.9	27.2	30.9	31.1	36.8	38.3	36.3	30.3	36.4	39.4	33.1	35.6	25.4	29.4	47.0	37.1	44.6	39.0	33.0	46.1	45.1	97.6	107.9	120.9	94.4	109.7	45.5	264	58
39	27.7	31.8	23.1	21.8	26.8	18.5	36.5	20.3	18.1	21.5	21.5	20.0	21.6	23.7	22.5	16.9	20.7	20.3	17.6	33.6	26.3	19.4	42.0	29.7	39.4	36.3	36.8	47.6	43.0	39.2	46.5	68.9	62.7	43.5	30.8	12.9	42
40	22.4	26.2	21.4	22.2	33.1	21.7	26.7	28.0	22.0	21.1	20.9	28.7	29.6	26.7	15.8	13.5	19.5	25.1	20.1	25.7	12.6	18.3	48.1	12.9	29.0	37.2	41.1	41.7	35.8	46.7	60.5	79.9	91.8	42.3	31.4	17.6	56
41	14.6	16.0	17.4	13.3	14.7	10.9	18.0	13.3	14.4	11.9	9.3	12.1	12.4	16.6	9.7	6.5	7.3	14.3	8.0	20.9	13.0	12.9	28.1	11.3	19.4	25.5	31.3	26.9	23.4	25.0	34.9	43.4	36.3	22.5	18.1	8.9	49
42	9.3	13.3	5.4	10.2	12.3	11.6	11.2	12.0	7.5	7.7	8.8	7.9	12.8	12.5	7.1	8.6	8.9	8.9	10.9	9.3	4.6	5.0	18.8	5.0	8.6	14.0	13.3	16.5	15.6	7.1	10.7	23.6	26.1	6.8	10.9	4.9	45
43	6.7	7.3	5.3	4.3	7.4	4.9	6.5	4.2	5.4	5.0	7.8	3.5	7.8	7.7	8.5	5.7	5.6	3.3	4.6	7.2	3.5	3.8	13.5	2.5	4.7	6.2	10.3	11.6	11.1	1.3	2.8	3.3	10.9	1.2	6.0	3.0	49
44	2.4	2.3	0.8	2.7	1.6	1.8	1.8	1.3	1.9	1.5	2.8	1.4	1.9	3.0	3.2	3.0	2.4	1.7	1.1	2.9	3.1	2.6	6.8	1.8	2.8	2.4	2.9	5.0	4.3	0.8	0.3	3.4	4.7	0.8	2.5	1.3	54
45	3.4	2.8	2.2	3.5	2.6	2.6	4.4	3.1	2.4	2.9	4.2	3.2	1.6	1.3	2.6	3.5	1.3	3.9	2.1	4.3	3.2	3.0	7.9	1.8	5.5	5.7	6.1	8.3	8.1	3.1	6.9	8.6	14.5	3.1	4.2	2.7	65
46	6.9	3.5	3.3	4.1	2.3	1.9	2.8	1.5	3.8	3.7	5.4	5.3	2.9	3.7	3.7	4.8	6.2	3.0	4.5	8.4	4.4	5.9	7.4	2.6	7.3	8.9	6.5	10.4	4.7	5.9	5.3	7.7	9.9	3.4	5.1	2.3	45
47	2.6	2.4	0.8	2.3	2.2	1.6	1.7	1.9	4.3	3.3	2.4	3.5	0.9	1.0	1.0	3.6	2.0	1.8	1.8	3.1	3.1	3.6	3.3	3.3	3.9	3.9	2.7	4.9	3.6	2.6	2.3	1.4	1.0	3.2	2.6	1.1	41
48	4.8	0.7	0.5	1.6	0.1	0.3	0.2	0.3	3.3	2.7	1.6	2.6	0.6	0.1	2.1	0.8	1.1	1.1	1.0	3.5	3.3	2.7	1.0	2.2	2.2	1.9	0.5	2.2	2.1	0.0	0.1	0.0	0.0	0.0	1.4	1.2	90
49	3.2	1.2	1.3	2.4	1.0	0.3	1.5	1.2	1.0	1.5	1.0	1.3	0.9	1.1	0.7	0.3	0.8	0.7	0.4	1.7	1.4	2.5	2.3	0.8	1.1	1.3	1.0	3.0	1.5	0.0	0.0	0.0	0.2	0.0	1.1	0.8	71
50	1.1	0.4	0.4	0.1	0.2	0.0	0.5	0.1	0.8	0.4	1.0	0.2	0.6	0.5	1.7	0.2	0.5	0.3	0.2	1.8	2.4	2.5	1.9	0.6	1.2	1.0	0.9	3.1	2.1	0.0	0.0	0.3	0.2	0.0	0.8	0.8	102
51	0.8	0.8	0.2	0.7	0.4	0.1	0.2	0.3	0.7	0.5	0.8	0.4	0.3	0.1	1.6	0.2	0.5	0.4	0.3	0.5	0.8	0.9	0.4	0.8	0.4	0.1	0.3	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.4	0.3	84
52	1.6	0.8	0.8	0.6	0.8	1.0	0.7	0.7	0.7	1.1	1.4	0.3	1.0	1.3	1.8	0.5	1.2	0.7	0.9	0.1	0.4	0.6	0.3	0.3	0.5	0.2	0.1	0.4	0.7	0.1	0.6	0.2	0.0	0.2	0.7	0.4	67

Table 18: Amount of dependable rainfall (@ 75 probability) occurred in different districts of Maharashtra

District	Rainfall (mm) at 75 % probability
Ahmednagar	419.6
Dhule	487.9
Jalgaon	525.2
Kolhapur	1567.4
Nandurabr	677.1
Nashik	831.5
Pune	676.5
Sangali	475.6
Satara	1194.5
Solapur	629.7
Thane	2511.3
Raigadh	2294.0
Ratnagiri	3077.6
Sindhudurg	3013.8
Palghar	2291.8
Aurangabad	533.2
Beed	605.2
Hingoli	752.2
Jalana	547.2
Latur	673.2
Nanded	604.8
Osmanabad	498.1
Parbhani	643.4
Akola	635.0
Amravati	707.1
Bhandara	1025.2
Buldhana	579.6
Chandrapur	939.5
Gadchiroli	1154.4
Gondia	1100.9

4.10. 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. 65). Around 78 percent of the *talukas* in the state showed no significant trend. However, the *talukas* in Kolhapur district showed declining trend in annual rainfall followed by Satara, Solapur, Aurangabad, Nanded and Yavatmal districts. On the other hand, increasing trend in annual rainfall is observed in many *talukas* of Nanded, Latur, Parbhani and also a few *talukas* of Hingoli, Beed and Jalana districts. In number of annual rainy days, no significant increasing / decreasing trend is seen in 78 per cent of *talukas*. Most of the *talukas* of districts in the state (Ahmednagar,

Jalana, Latur and Beed) showed an increasing trend (Fig. 66). 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 few *talukas* of all four regions in the state.

For the SWM rainy season, in 3 out of 17 *talukas* a declining trend was observed in Kolhapur district (Fig. 67). At the same time, increasing tendency in southwest monsoon rainfall is observed in few numbers of *talukas* of Nanded and Aurangabad followed by Beed, Latur, Ahemadnagar, Jalgaon and Parbhani districts. The trend of number of rainy days during the southwest monsoon season showed same pattern as in the case of amount of rainfall (Fig. 68). However, a declining trend is seen in about few *talukas* in the state.

4.10. 1. Trends in receipt of heavy rainfall events in various districts of Maharashtra

Heavy / very heavy rainfall events result in flash floods leading soil erosion, landslides in hilly terrain and 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 *taluka* level daily rainfall data for the state of Maharashtra has been assembled. Mann-Kendall test has been applied to understand the significance of heavy rain events.

4.10.2. 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 288 *talukas* and in the more than 100 mm category, 315 *talukas* did not show any significant difference (Fig. 69 and 70). However, significant increasing trend is noted in many *talukas* of Ratnagiri, Pune, Raigadh, Nanded, Palghar, Parbhani, Osmanabad, and Beed districts. A declining trend is observed in Solapur, Gadchiroli, Jalgaon, Parbhani, Kolhapur, Nagpur, Amravati, Bhandara, Yavatmal, Buldhana and Satara districts under 75-100 mm category.

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[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.

4.10.3. Heavy rainfall events during Southwest monsoon season in Maharashtra

Almost same pattern as that of annual rainfall is noted in the heavy rainfall trends during the SWM period across Maharashtra. The state as a whole, showed significant increasing and declining trends in 6 and 8 *talukas*, respectively under 75-100 mm category. The increasing trend is seen in Thane, Buldhana, followed by Nanded and Wardha. Declining trend is observed in Kolhapur, Raigadh Satara, Buldhana, Yavatmal and Parbhani districts (Fig. 71). It is evident from the map that a few *talukas* of Thane in the *Kokan*, Buldhana and Wardha districts in the *Vidharbha* region and Nanded and Beed districts in *Marathwada* region showed significantly increasing trend under more than 100 mm category (Fig. 72). On the other hand, declining tendency in frequency of more than 100 mm / day is evident in the coastal part of the state (Sindhudurg and Raigadh) and also in the *Vidharbha* region (Buldhana and Yavatmal).

From the above, it is clear that majority of the *talukas* 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 *talukas* in 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 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 rainfall) on monthly basis. Spatial maps are prepared by estimating PET normals for each districts. 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. 73 to 77.

4.11.1. Annual

The mean daily PET on an annual basis ranged from 4.5 to 5.4 mm/day in the state. Spatial differences are noticed. Highest PET (5.3 to 5.4 mm/day) is observed in majority area of Parbhani, Solapur, Dhule and Jalgaon district (Fig. 73). Large geographical area of the state experience PET values in the range of 4.9 to 5.2 mm/day. Lowest PET (4.5 to 5.o mm/day) values are recorded in Igatpuri district which is at high altitude.

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[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 19: Per cent area showing increasing/decreasing trend in annual rainfall in different districts of Maharashtra

District		IT 99%	IT 95 %	IT 90 %	DT 99%	DT 95 %	DT 90 %	No Trend	
Ahemadnagar		1	Nil	2	Nil	Nil	Nil	97	9
Dhule		Nil	Nil	Nil	Nil	Nil	Nil	100	10
Jalgaon		2	Nil	1	Nil	Nil	Nil	97	9
Kolhapur		Nil	Nil	Nil	1	2	Nil	97	9
Nandurbar		1	Nil	Nil	Nil	Nil	Nil	98	5
Nashik		1	Nil	Nil	Nil	Nil	Nil	99	10
Pune		Nil	Nil	Nil	Nil	Nil	Nil	100	6
Sangli		1	Nil	Nil	Nil	Nil	Nil	100	3
Satara		Nil	Nil	1	Nil	Nil	2	97	7
Solapur		Nil	Nil	Nil	Nil	1	1	98	7
Thane		Nil	1	Nil	Nil	Nil	Nil	99	4
Raigadh		Nil	Nil	Nil	Nil	Nil	1	100	14
Ratnagiri		Nil	Nil	1	Nil	Nil	Nil	99	8
Sindhudurg		Nil	Nil	1	Nil	Nil	Nil	99	7
Palghar		Nil	1	Nil	Nil	Nil	1	98	5
Aurangabad		1	Nil	Nil	Nil	1	1	97	6
Beed		4	Nil	Nil	Nil	Nil	Nil	96	7
Hingoli		2	Nil	Nil	Nil	Nil	Nil	98	3
Jalana		3	Nil	Nil	Nil	Nil	Nil	97	5
Latur		5	Nil	Nil	Nil	Nil	Nil	95	5
Nanded		8	Nil	Nil	Nil	1	1	92	6
Osmanabad		1	Nil	1	Nil	Nil	Nil	99	6
Parbhani		4	Nil	Nil	Nil	Nil	1	96	5
Akola		Nil	Nil	Nil	Nil	Nil	Nil	100	7
Amravati		1	Nil	Nil	Nil	Nil	1	98	12
Buldhana		Nil	Nil	1	Nil	Nil	Nil	99	12
Chandrapur		Nil	Nil	Nil	Nil	Nil	Nil	100	15
Gadchiroli		Nil	Nil	Nil	Nil	1	Nil	99	11
Gondia		Nil	Nil	Nil	Nil	Nil	Nil	100	8
Nagpur		Nil	Nil	1	Nil	Nil	Nil	99	11
Wardha		Nil	Nil	Nil	Nil	Nil	Nil	100	8
Washim		Nil	Nil	Nil	Nil	Nil	Nil	100	6
Yavatmal		Nil	Nil	Nil	Nil	1	1	98	12

Table 20: Per cent area showing increasing/decreasing trend in Southwest rainfall in different districts of Maharashtra

District		IT 99%	IT 95 %	IT 90 %	DT 99%	DT 95 %	DT 90 %	No Trend	No Trend
Ahemadnagar		1	Nil	Nil	Nil	Nil	1	98	10
Dhule		Nil	2	Nil	Nil	Nil	Nil	98	8
Jalgaon		Nil	1	Nil	Nil	Nil	Nil	99	9
Kolhapur		Nil	Nil	Nil	1	1	Nil	98	9
Nandurbar		Nil	Nil	Nil	Nil	Nil	Nil	100	6
Nashik		1	2	Nil	Nil	Nil	Nil	97	8
Pune		Nil	Nil	Nil	Nil	Nil	Nil	100	6
Sangli		1	Nil	Nil	Nil	Nil	Nil	99	3
Satara		Nil	1	Nil	1	Nil	1	97	7
Solapur		Nil	Nil	1	Nil	Nil	Nil	99	8
Thane		Nil	1	Nil	Nil	Nil	Nil	99	4
Raigadh		Nil	Nil	Nil	Nil	Nil	Nil	100	15
Ratnagiri		Nil	Nil	1	Nil	Nil	Nil	99	8
Sindhudurg		Nil	Nil	Nil	Nil	Nil	Nil	100	8
Palghar		Nil	1	Nil	Nil	Nil	Nil	99	6
Aurangabad		2	2	2	Nil	Nil	Nil	94	3
Beed		4	Nil	2	Nil	Nil	Nil	94	5
Hingoli		2	Nil	Nil	Nil	Nil	Nil	98	3
Jalana		3	Nil	Nil	Nil	Nil	Nil	97	5
Latur		5	Nil	Nil	Nil	Nil	Nil	95	5
Nanded		7	Nil	1	Nil	Nil	Nil	92	8
Osmanabad		1	Nil	1	Nil	Nil	Nil	98	6
Parbhani		4	Nil	Nil	Nil	Nil	Nil	96	5
Akola		Nil	Nil	Nil	Nil	Nil	Nil	100	7
Amravati		1	Nil	2	Nil	Nil	Nil	97	11
Buldhana		Nil	Nil	1	Nil	Nil	Nil	99	12
Chandrapur		Nil	Nil	Nil	Nil	Nil	Nil	100	15
Gadchiroli		Nil	Nil	Nil	Nil	1	Nil	99	11
Gondia		Nil	Nil	Nil	Nil	Nil	Nil	100	8
Nagpur		Nil	Nil	Nil	Nil	Nil	1	99	11
Wardha		Nil	Nil	Nil	Nil	Nil	Nil	100	8
Washim		Nil	Nil	Nil	Nil	Nil	Nil	100	6
Yavatmal		Nil	Nil	Nil	Nil	Nil	1	99	13

4.11.2. Southwest monsoon season

This is the main rainy season of the state. PET rates of major geographical area of the state ranged from 3.3 to 5.4 mm/day during this season. Highest rates (4.9 to 5.4 mm/day) are noted in parts of Dhule, Jalgaon, Rahuri, Solapur, Akola, Amravati, Gadchiroli, Wardha, Washim, Parbhani, Beed and Latur districts (Fig. 74). Lowest rates (3.3 to 4.8 mm/day) are noted in parts of Dapoli, Kudal, Karjat and Igatpuri, Kolhapur districts which falls under costal region and high altitude.

4.11.3. Post monsoon season

During this season major area of state experiences PET rates in the range of 3.7 to 4.7 mm/day. Like in the case of annual and SWM season, parts of Gadchiroli, Yavatmal and Kolhapur, Igatpuri districts that fall under tribal zone and high altitude showed lowest PET rates (3.7 to 4.4 mm/day) (Fig. 75).

4.11.4. Summer season

Summer is the hottest season of the year and PET values for major geographical area ranged between 5.5 to 7.2 mm/day. Parts of Gondia, Gadchiroli, Akola, Solapur, Parbhani districts and entire Jalgaon district showed highest PET values (6.8 to 7.2 mm/day) (Fig. 76).

4.11.5. Winter season

During winter season highest PET (4.5 to 5.2 mm/day) are noted in parts of Jalgaon and Kudal districts and lowest values (3.9 to 4.4 mm/day) in parts of Buldhana, Gondia, Aurangabad and Niphad districts (Fig. 77).

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 Maharashtra, but its intensity differs from region to region. The frequency of moderate and severe meteorological droughts were computed based on departures from normal annual rainfall for all the *talukas* of Maharashtra (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 10 to 20 per cent occurs in Jalana, Nashik, Buldhana, Akola, Beed, Aurangabad, Palghar, Ratnagiri, Raigadh, Thane, Solapur, Nanded, Jalgaon, Dhule and Kolhapur districts. In fact, less area in the state has 20 and 30 per cent probability of the occurrence of moderate drought (Fig. 78). Lowest probability has been observed in Phulambri *taluka* of Aurangabad district and highest probability has been observed in Bhoom and Kalamb *talukas* of Osmanabad district (58%).

Around 80 per cent of the *talukas* 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 *talukas* of Ahmednagar, Jalgaon, Dhule and Akola districts (Fig. 79). Highest severe drought probability is seen in Pune (18 %), Chandrapur, Yavatmal (13 %) and *talukas* of Sangali and Solapur, (11%).

4.12.1. Drought frequency based on Standardized Precipitation Index

Probabilities of occurrence of drought over Maharashtra 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 *talukas* of Maharashtra based on SPI methodology were computed for three time scales (Annual - 12 months scale, Southwest monsoon - 4 months scale and Post monsoon - 3 months scale) for 326 *talukas* 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 22. Drought event begins any time when the SPI is continuously negative and ends when the SPI gains a positive value.

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

Table 21 Categorization of climates based on SPI

SPI	Category
More than +2.0	Severely wet
1.5 to 1.99	Very Wet
1/.00 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

4.12.2. Drought probability on annual scale

Probability for near normal rainfall is above 50 per cent for all the 328 *talukas* considered for analysis. It is interesting to note that highest probability (89%) is observed in Shirur Anantpal, Udgir taluka of Latur district followed by Loha *taluka* in Nanded district and Kamptee *taluka* in Nagpur (89%).Though they are situated in a semi-arid climatic region, near normal conditions is being expected over these *talukas*. In *talukas* from coastal *Kokan* 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 128 *talukas* out of 328 *talukas* across the state for near normal condition (Fig. 80 a). Lowest probability for normal conditions is noted in Murtijapur *talukas* in Akola district (50%) followed by Sangrampur in Buldhana district (53%) and Digras in Yavatmal district (54%). Highest probability of occurrence for moderately dry condition is seen in Manora in Washim district and Parseoni Nagpur district (21%) followed by 20 per cent probability in Ralegaon in Yavatmal district, Chopda in Jalgaon district (Fig. 80 b). It can be inferred that in 2 out of 10 years moderate dry conditions can be expected in the above *talukas*. The probability of occurrence of severe and extremely dry conditions is almost nil in 86 and 139 *talukas*, respectively. Highest probability

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

(13%) under severe dry category has been noted in 2 *talukas* (Fig. 80 c) and extremely dry conditions may prevail with a 21% probability in Mauda *taluka* of Nagpur district (Fig. 80 d).

4.12.3. Drought probability during Southwest monsoon season

Probability for near normal condition during Southwest monsoon is above 50 per cent for all 328 *talukas*. Probability of 70% and above for near normal conditions has been noted in nearly all *talukas* of Maharashtra (323 out of 328). However, the highest probability is observed in Kamptee *taluka* (95%) in Nagpur district followed by Lohar in Nanded district (83%) Jalkot in Latur district (81%) and Kagal in Kolhapur district (80%). Lowest probability of 51 per cent in Sindkhed Raja (Buldhana district) and Mauda (Nagpur) *talukas* has been recorded (Fig. 81 a). In the case of moderately dry category, highest probability of 28% and above noted in two *talukas viz.,* Sindkhed Raja, Buldhana (32%) and Jivati (32%), Chandrapur district (Fig. 81 b). Very low probability for moderately dry condition to occur has been observed in Bhokardan (Jalana district), Deglur (Nanded district), Shrigonda (Ahemadnagar district), Mangalwedha (Solapur district) and Wani (Yavatmal district) *talukas*. Like-wise, probability for severely and extremely dry condition to occur has been noted in 248 and 178 *talukas*, respectively (Fig. 81 c). However, probability of occurrence of severely dry conditions is highest (16%) in Lakhni and Karanja *talukas* in Bhandara and Washim district respectively. While the Lonar *talukas* of Buldhana district the probability of extremely dry condition is highest (26%) in Kalmeshwar, Kuhi, Katol and Mauda *talukas* of Nagpur district (16%) (Fig. 81 d).

4.12.4. Drought probability during Post monsoon season

Probability for near normal conditions is above 50% during the post monsoon season in all the 328 *talukas* studied. Highest probability of 93 per cent has been noted in Korpana *taluka* (Chandrapur district) followed by 92 per cent Mantha *taluka* (Jalana district), 85 per cent in Bhusaval *taluka* (Jalgaon district) and 83 per cent in Renapur *taluka* (Latur district) and lowest probability of 53 per cent observed in Mahad *taluka* (Raigadh district) and Talasari *taluka* (Palghar district) (Fig. 82 a). Probability of moderately dry condition above 20% noted in Chalisgaon, Jamner and Yaval *taluka* (Jalgaon district), Parbhani *taluka* (Parbhani district) Jalgaon Jamod *taluka* (Buldhana district) 22 per cent and Nagbhid *taluka* (Chandrapur district) 24 per cent. (Fig. 82 b). Severely and extremely dry conditions were not noted in 208 *talukas* and 235 *talukas*, respectively. Highest probability (11%) for severely dry category has been observed in Hinganghat *taluka* of Wardha district (Fig. 82 c) and extremely dry (8%) in Kalmeshwar *taluka* of Nagpur district (Fig. 82 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 *talukas* 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 22), *talukas* have been classified into different climatic types a and thematic map has been prepared. It is presented as Fig. 83.

Results presented in Fig. 83 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 *talukas* in each district are semi-arid. Majority of the *talukas* in *Marathwada* region, some talukas in Madhya *Maharashtra* and *Vidharbha* reigion are semi-arid.

Dry sub-humid climate, which is a transition between dry and moist tropical climates prevails over districts like Gadchiroli, Gondia and many *talukas* of Bhandara, Chandrapur, Sangli, Satara, Pune and Nashik districts. Among the coastal districts, entire *Kokan* reion is per-humid. Moist sub-humid and humid B1, B2 and B3 type climate is noted in parts of Kolhapur, Sangli, Satara, Pune, Nashik and Thane district. While entire district of Thane having a humid B4 type climate.

Table 22 Classification of climates according to moisture index

Moisture index (%)	Climate type (Symbol)
Above 100	Pre - 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)

[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 ET0 calculator (FAO, Penman-Monteith method). Monthly values for precipitation and PET were considered for computing LGP for all the *talukas*. Thematic map was prepared depicting the spatial distribution of LGP (Fig. 84).

Most of the state has LGP between 120-150 days. It covers all districts of *Marathwada,* some districts of *Vidharbha* and *Madhya Maharashtra* region. LGP is > 180 days is observed in Raigadh, Thane, Raigadh and Ratnagiri districts. It is in the range of 150 to 180 days in parts of Kolhapur, Satara, Nashik, Solapur, Gadchiroli, Gondia, Chandrapur and Bhandara districts.

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 *talukas*. Weekly rainfall for all the *talukas* 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, 200 and 250 mm in the root profile (Fig. 85 a to e). It is assumed that the season commences in a week after the 23rd SMW if the MAI value of two consecutive weeks is $\geq$0.5. Likewise, growing season is assumed to end if MAI is $\leq$ 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 *taluka* is computed and presented in Table 23 for four soil water holding capacities (50, 100, 150, 200 and 250) (Fig. 86 a to e).

4.14.3. End of the season

Growing season terminates early (by 42nd SMW) in all districts of *Vidhabha* region in soils having low water capacity (50 mm) and by 51 SMW in soils having a water holding capacity of 250 mm. Growing season terminates early in most of the *Mar*athwada *and Madhaya Maharashtra* districts (in 43 to 51 SMW) and (in 43 to 52 SMW) respectively compared to coastal *Kokan* districts (in 44 to 56 SMW) (Fig. 87 a to e). Crop growing season extends by two weeks on an average with a corresponding increase

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

in water holding capacity of the soil by 50 mm. On an average, the length of growing season is longest in coastal *Kokan* districts (22 weeks) followed by *Mar*athwada, *Madhaya Maharashtra* and *Vidhabha* districts (18 weeks) for soils having water holding capacity of 50 mm. The figures for soils having 100 mm capacity are 25, 20, 20 and 20 respectively. For soils having 150 mm water holding capacity the average duration for coastal, *Konkan* and rest of regions districts are 28 and 22 respectively. In soils having 200 mm water holding capacity, the length of growing season represents an average for 31 and 24 weeks in Coastal, *Konkan* and rest of regions districts, respectively. While the soils having 250 mm water holding capacity, the length of growing season on average for 34, 26, 25 and 26 weeks in Coastal, *Kokan, Madhaya Maharashtra, Marathwada* and *Vidhabha* districts, respectively.

Table 23 Start, end and duration of crop growing season in soils with different water holding capacities in various districts of Maharashtra

	50			100			150			200			250		
District	**Start**	**End**	**Duration**	**Start**	**End**	**Duration**	**Start**	**End**	**Duration**	**Start 200**	**End 200**	**Duration**	**Start**	**End**	**Duration**
Ahemadnagar	26	43	18	26	46	20	27	48	22	27	50	24	27	52	26
Dhule	26	43	18	26	46	20	27	48	22	27	50	24	27	52	26
Jalgaon	26	43	18	26	45	20	27	47	22	27	49	24	27	51	26
Kolhapur	26	43	18	26	46	20	27	48	22	27	50	24	27	52	26
Nandurbar	26	43	18	26	46	20	27	48	23	27	50	25	27	52	27
Nashik	26	43	18	26	45	20	27	48	22	27	50	24	27	52	26
Pune	26	43	18	26	46	20	27	48	22	27	50	24	27	52	26
Sangali	26	43	18	26	46	20	26	48	22	27	50	24	27	52	26
Satara	26	43	18	26	46	20	27	48	22	27	50	24	27	52	26
Solapur	26	43	18	26	46	20	27	48	22	27	50	24	27	52	26
Palghar	23	44	22	23	47	25	23	50	28	23	53	31	23	56	34
Raigad	23	44	22	23	47	25	23	50	28	23	53	31	23	56	34
Ratnagiri	23	44	22	23	47	25	23	50	28	23	53	31	23	56	34
Sindhudurg	23	44	22	23	47	25	23	50	28	23	53	31	23	56	34
Thane	23	44	22	23	47	25	23	50	28	23	53	31	23	56	34
Aurangabad	26	43	18	26	45	20	26	47	22	27	49	23	27	51	25
Beed	26	43	18	26	45	20	26	47	22	27	49	24	27	51	25
Hingoli	26	43	18	26	45	20	26	47	22	26	49	24	27	51	25
Jalana	26	43	18	26	45	20	26	47	22	27	49	24	27	51	25
Latur	26	43	18	26	45	20	26	47	22	27	49	24	27	51	25
Nanded	26	43	18	26	45	20	26	47	22	27	49	24	27	51	25
Osmanabad	26	43	18	26	45	20	26	47	22	27	49	23	27	51	25
Parbhani	26	43	18	26	45	20	26	47	22	27	49	23	27	51	25
Akola	25	42	17	26	44	19	26	46	22	26	49	24	26	51	26
Amravati	25	42	18	26	44	20	26	47	22	26	49	24	26	51	26
Bhandara	25	42	18	25	44	20	26	47	22	26	49	24	26	51	26
Buldhana	25	42	18	26	44	20	26	47	22	26	49	24	26	51	26
Chandrapur	25	42	18	26	44	20	26	47	22	26	49	24	26	51	26
Gadchiroli	25	42	18	25	44	20	26	47	22	26	49	24	26	51	26
Gondia	25	42	18	25	44	20	26	47	22	26	49	24	26	51	26
Nagpur	25	42	18	25	44	20	26	47	22	26	49	24	26	51	26
Wardha	25	42	18	25	44	20	26	47	22	26	49	24	26	51	26

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 32 *districts* and hence the trends were computed for these *districts*. The geospatial maps were prepared based on these data points by interpolation.

4.15.1. Episodes of maximum one-day rainfall

Results presented in Fig. 88 show that no significant increasing or decreasing trend is noticed in majority of *districts* (4 out of 32 *districts*) regarding maximum one-day rainfall. An increasing trend is observed in one *taluka* only. This is located in Nashik *district*. Declining trend is noted in 2 *districts* in Beed, Akola districts and Kolhapurr districts. It may be concluded that high daily rainfall episodes show an increasing trend only over the *Madhya Maharashtra* region while a declining trend is noted over the *Mar*athwada, *Vidharbha* and *Madhya Maharashtra* region.

4.15.2. Trends in maximum cumulative amount of five-day rainfall events across different *talukas* in Maharashtra

A significant increasing trend in maximum 5-day cumulative rainfall has been noted in two *talukas viz.,* Nagpur and Nashik *districts* (Fig. 89). A declining trend is observed in Wardha, Karjat and in Solapur *districts* 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 32 *districts* analyzed only three showed increasing tendency in mean daily rainfall intensity. On the other hand only seven *viz.,* Akola and Aurangabad, Beed, Hingoli, Jalana, Nanded and Solapur *districts* showed a declining trend (Fig. 90).

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 91 per cent (29 out of 32 *districts*) analyzed. However, an increasing trend has been evident in two *districts* out of which one is located in Yavatmal and one in Jalana districts. On the other hand, a declining trend is observed in the length of dry spell in the *Chandrapur* district (Fig. 91). Thus, it can be inferred that increasing / decreasing trend in length of dry spell has occurred in very few pockets spread across the state.

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

There is no significant increasing or decreasing trend in the length of continuous wet spells in, 8 out of 32 *districts* in the state (Fig. 92). The length of wet spells showed an increasing trend in 4 *districts* out of which 4 *districts* are located in the Marathwada region and two *districts* are situated in the *Madhaya Maharashtra* region. A declining trend is observed only in two *districts viz.,* Gondia and Nashik.

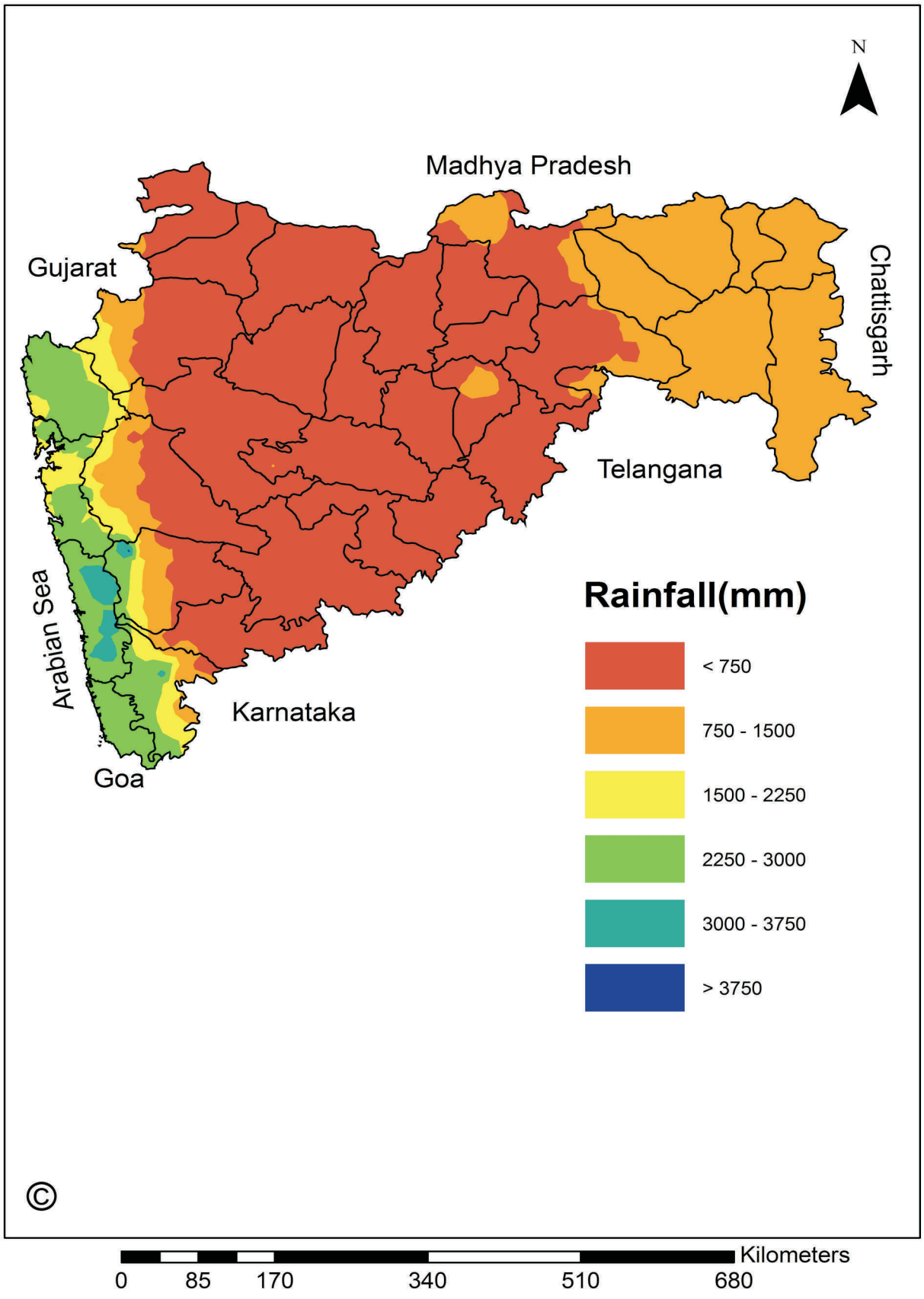

Fig. 64: Area with ≥ 75% probable annual rain in Maharashtra

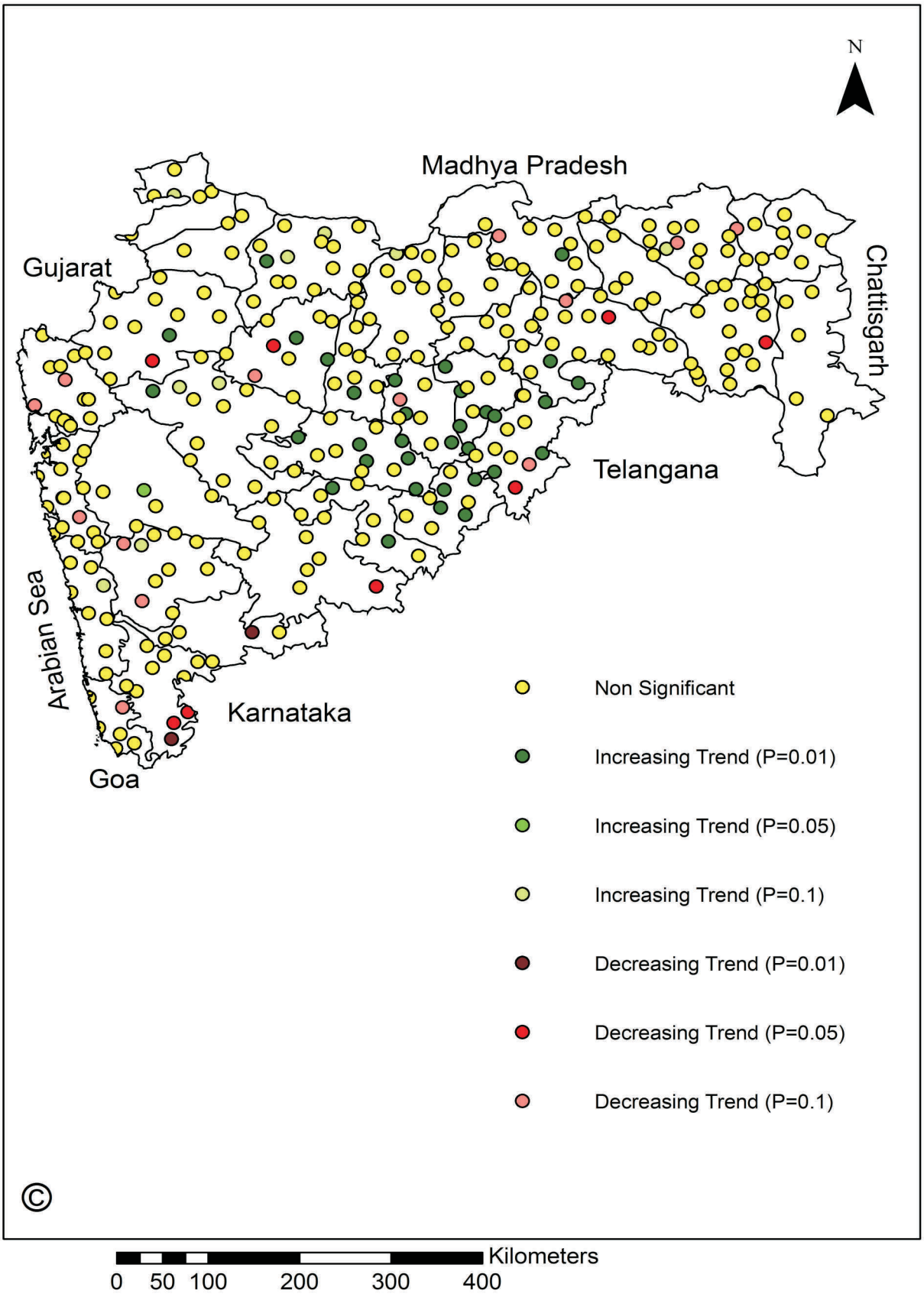

Fig. 65: *Tahsils* in Maharashtra showing a change in the annual rainfall pattern

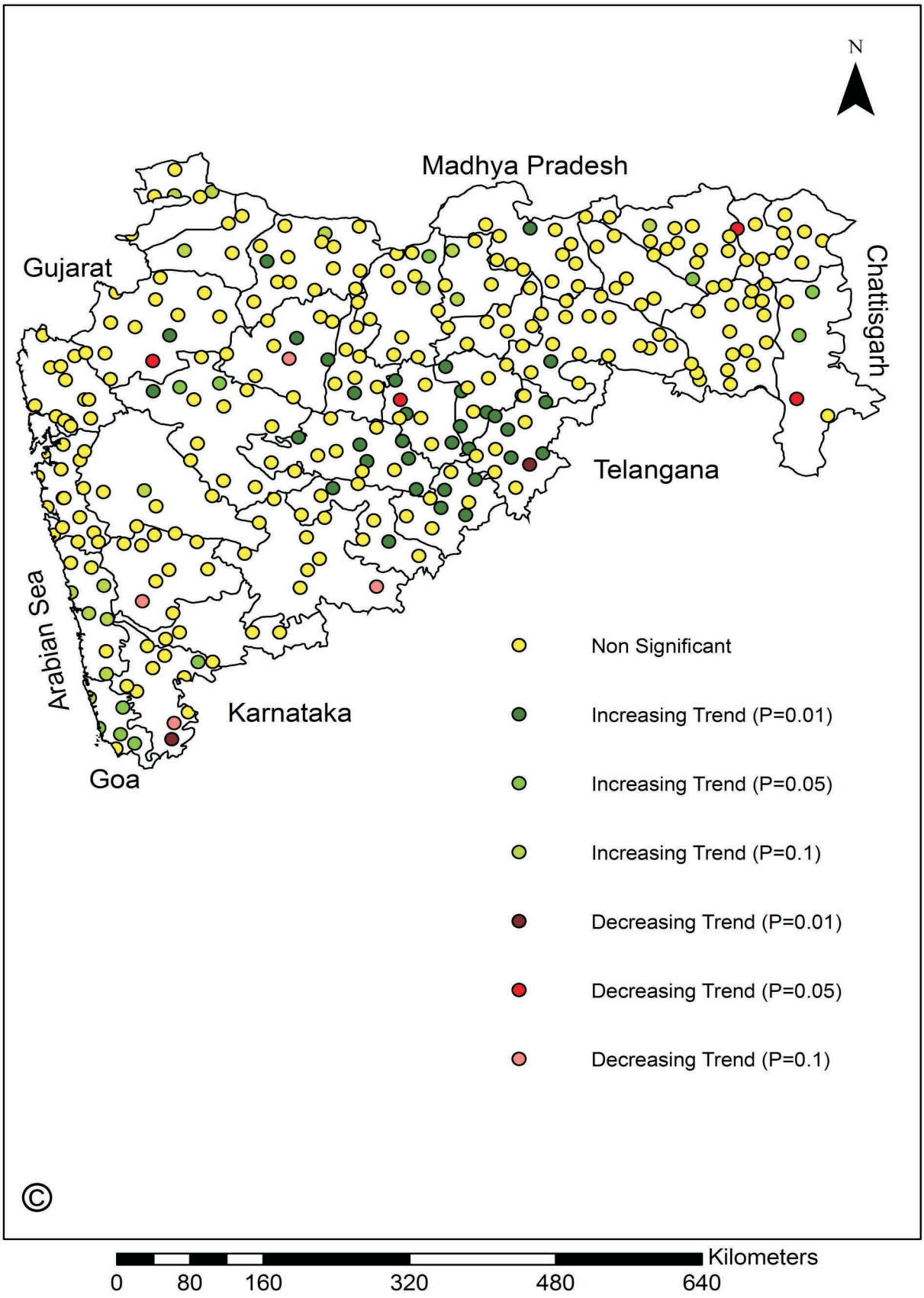

Fig. 66: *Tahsils* in Maharashtra showing a change in the annual rainy days pattern

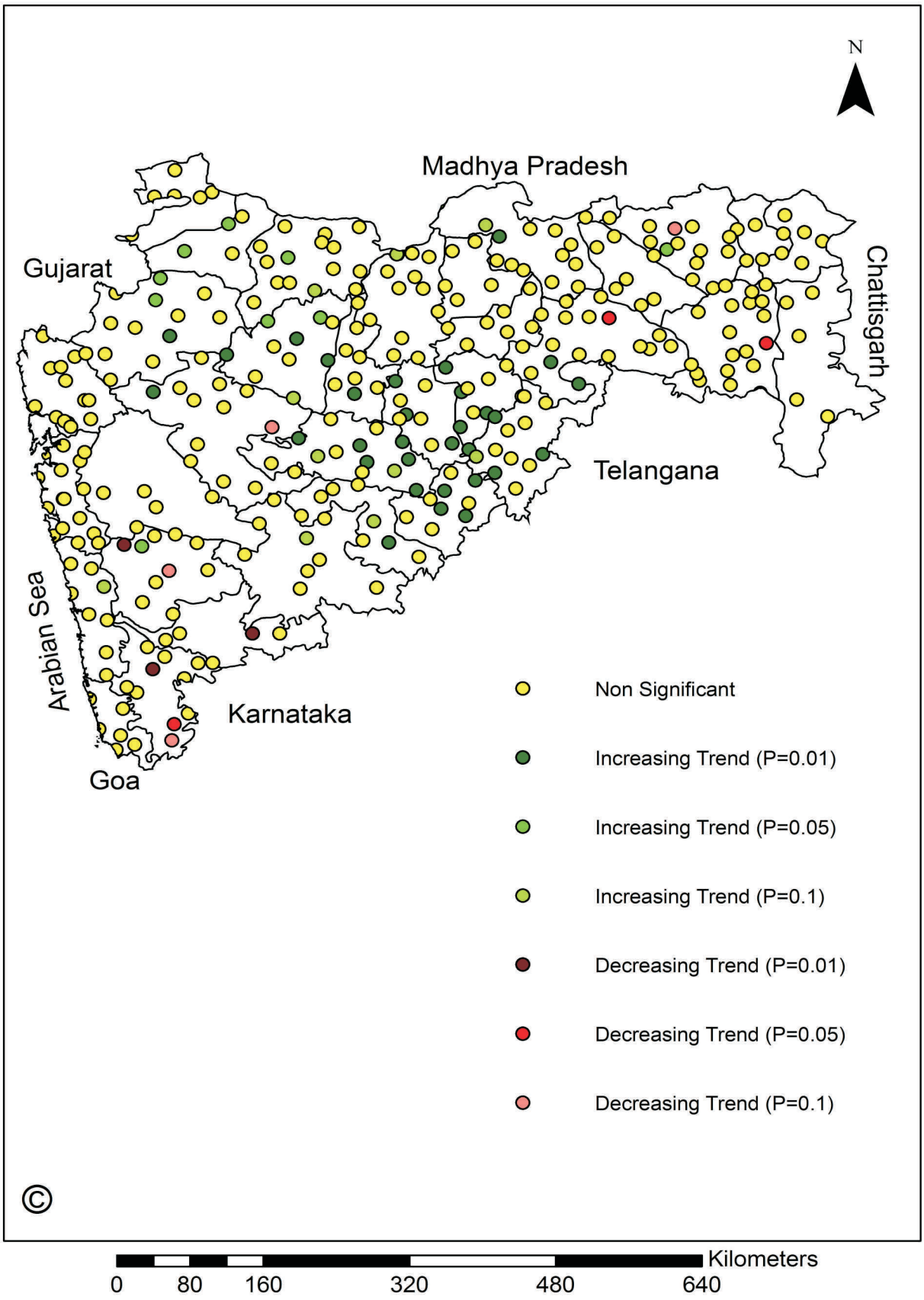

Fig. 67: *Tahsils* in Maharashtra showing a change in the southwest monsoon season rainfall pattern

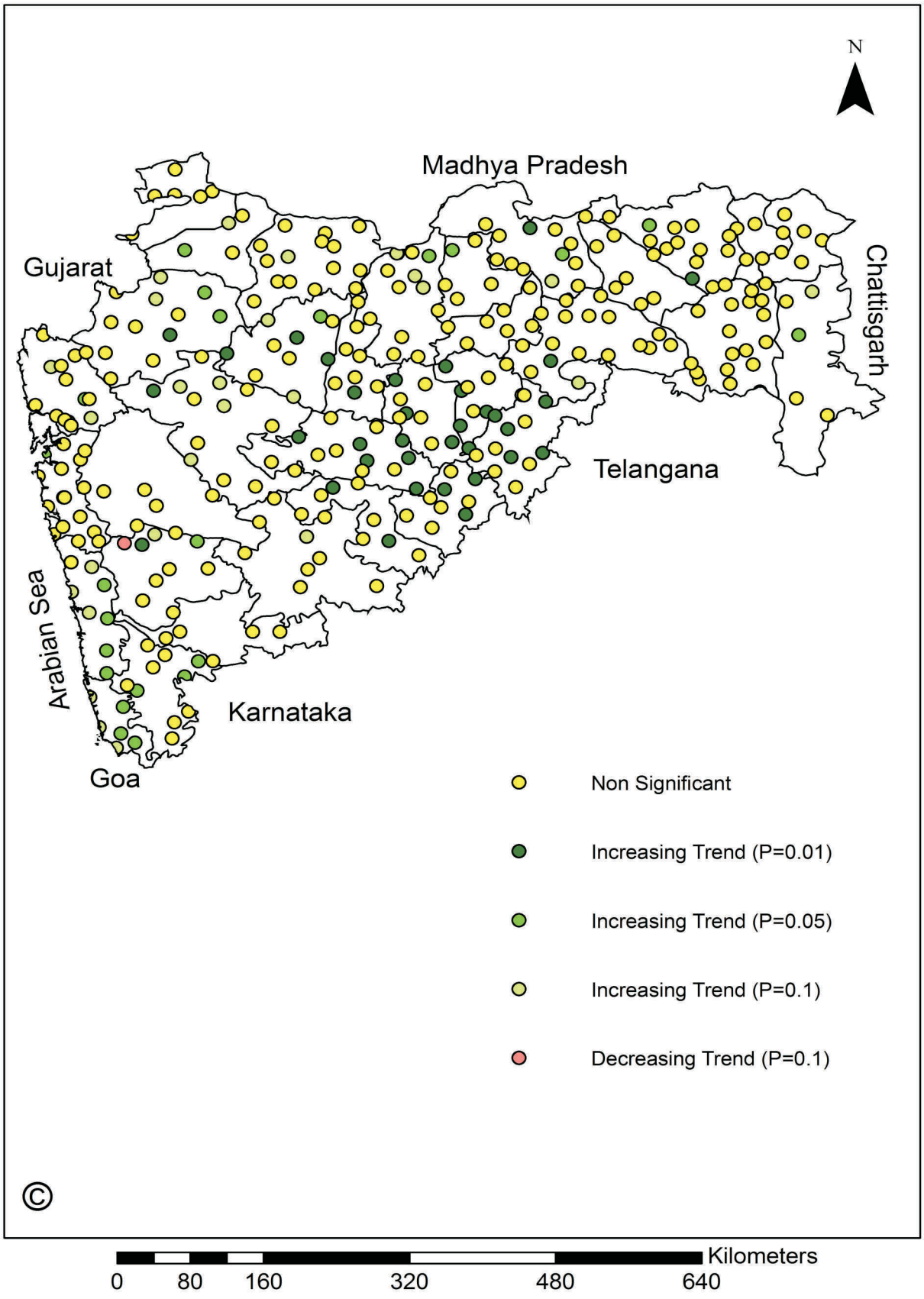

Fig. 68: *Tahsils* in Maharashtra showing a change in the number of rainy days pattern during Southwest monsoon season

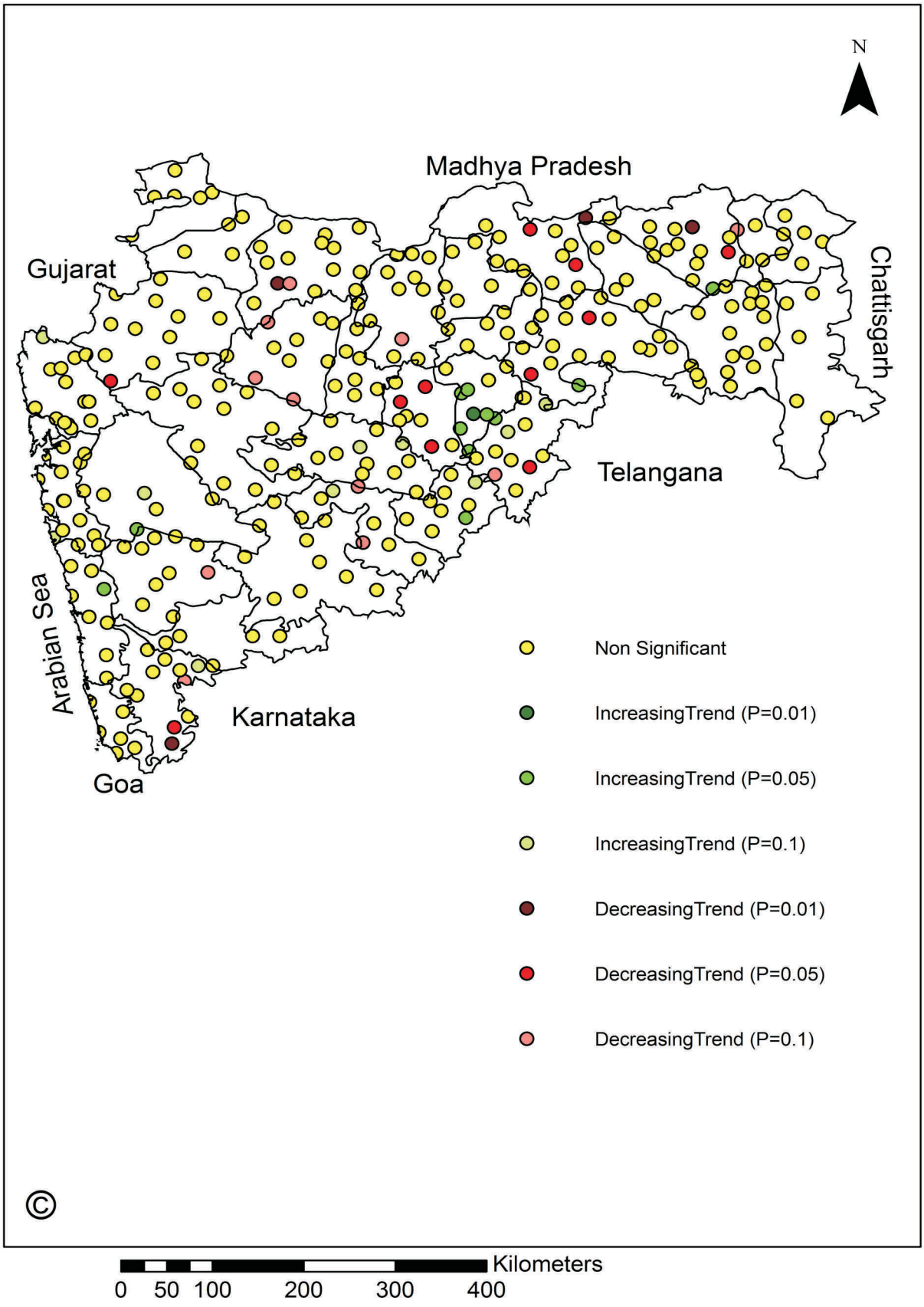

Fig. 69: *Tahsils* in Maharashtra showing changes in annual rainfall events in the 75-100 mm category

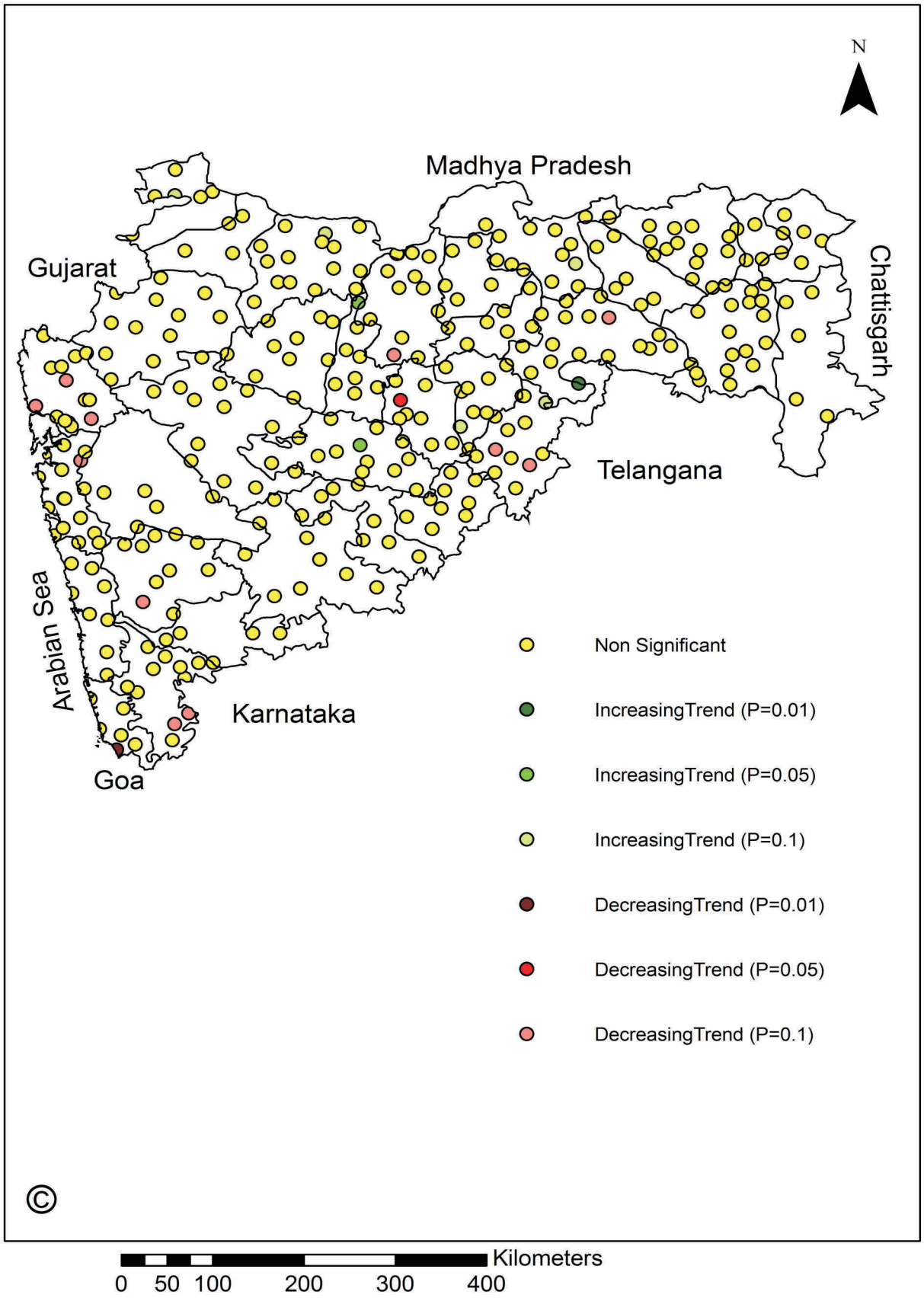

Fig. 70: *Tahsils* in Maharashtra showing changes in annual rainfall events in the >100 mm category

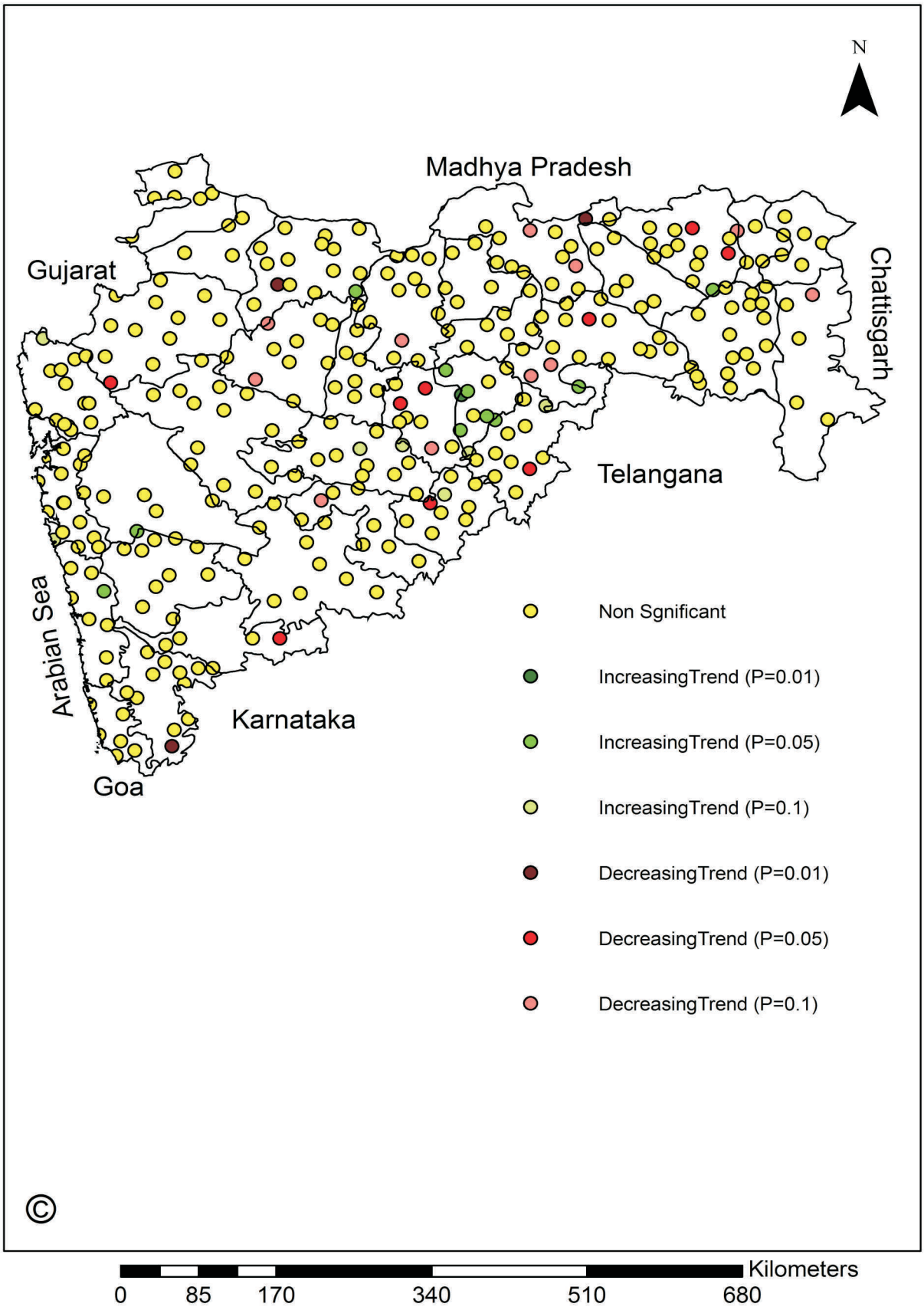

Fig. 71: *Tahsils* in Maharashtra showing changes in Southwest monsoon rainfall events in the 75-100 mm category

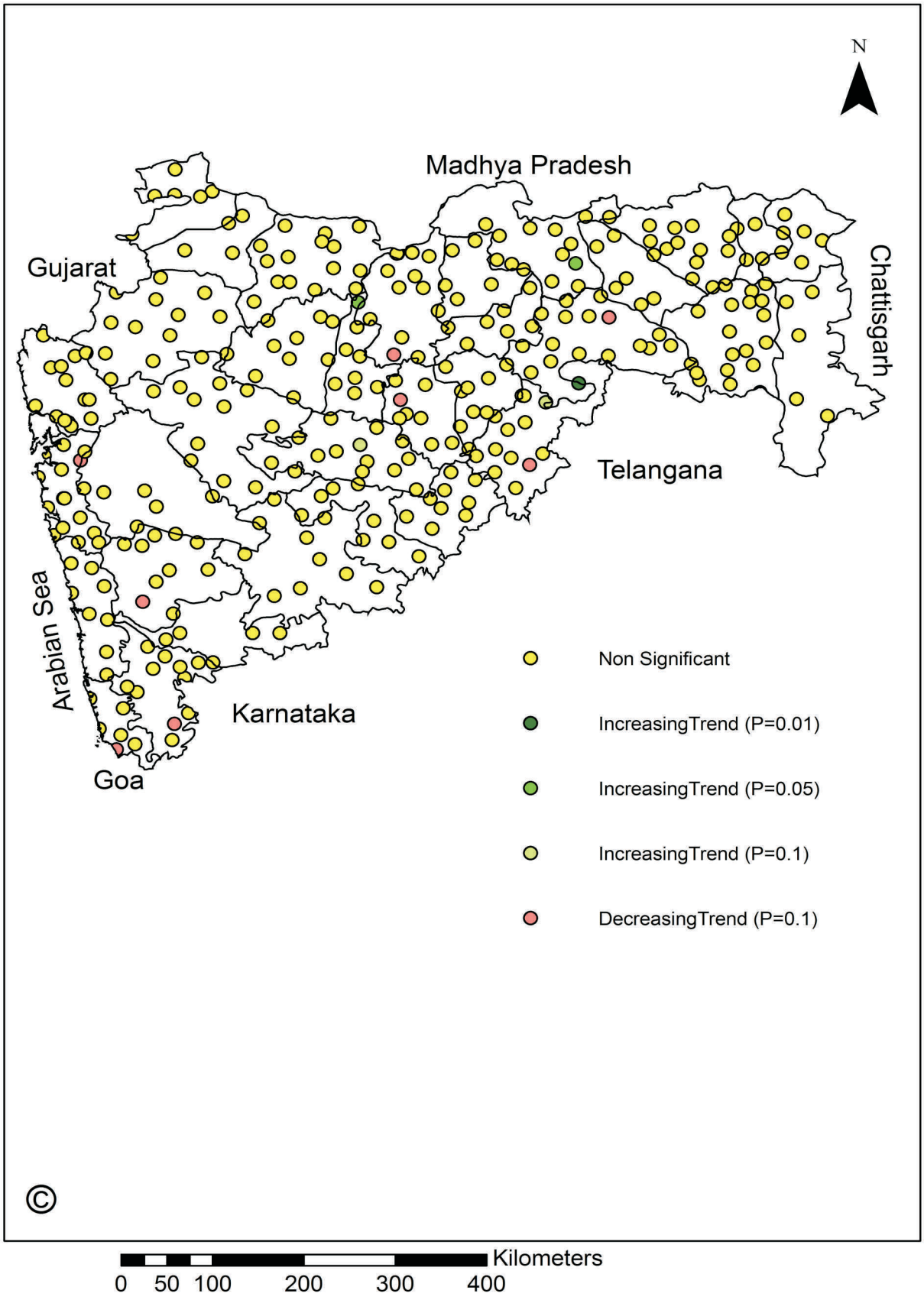

Fig. 72: *Tahsils* in Maharashtra showing changes in Southwest monsoon rain events in the >100 mm category

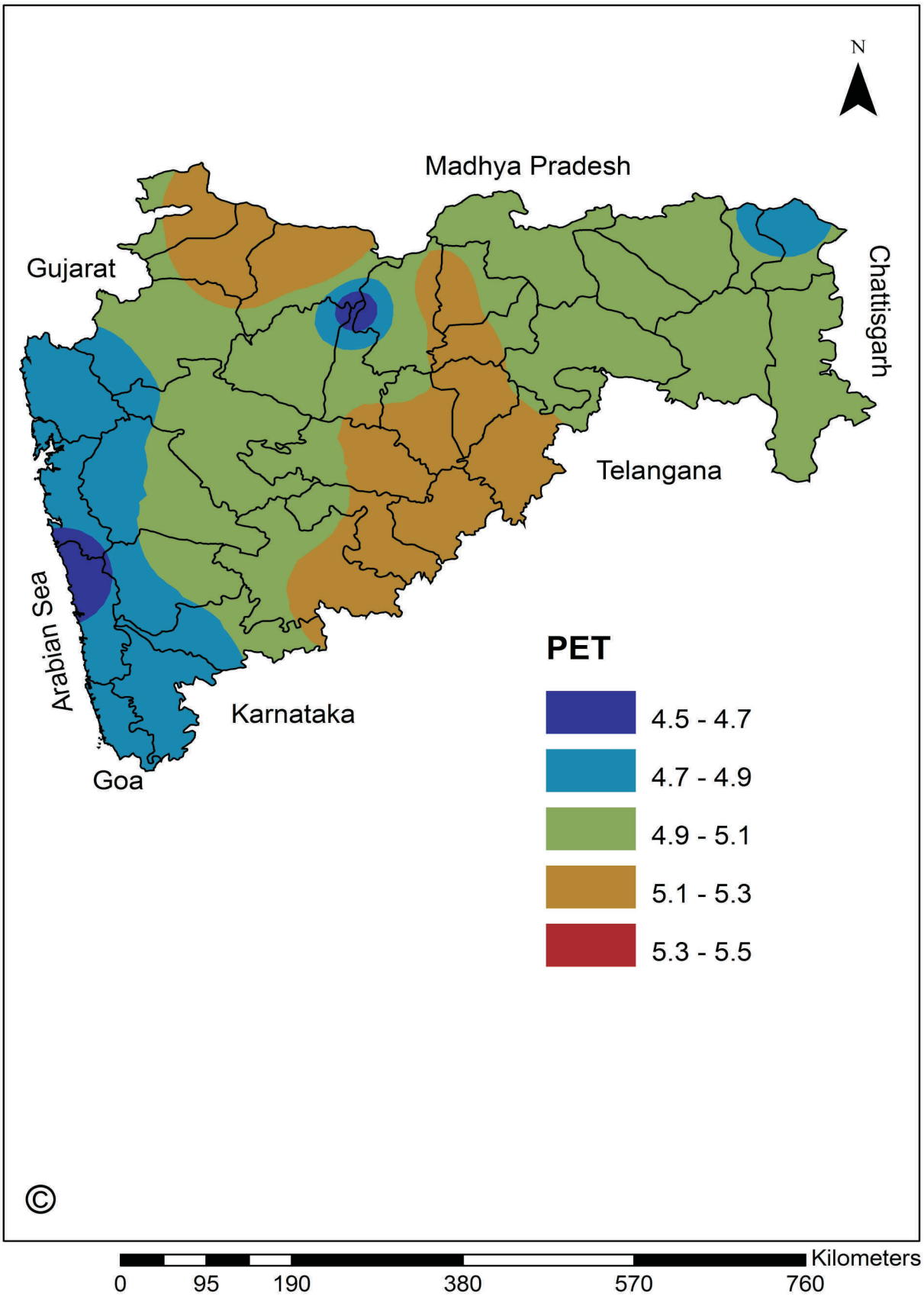

Fig. 73: Annual potential evapotranspiration (mm/day) over Maharashtra

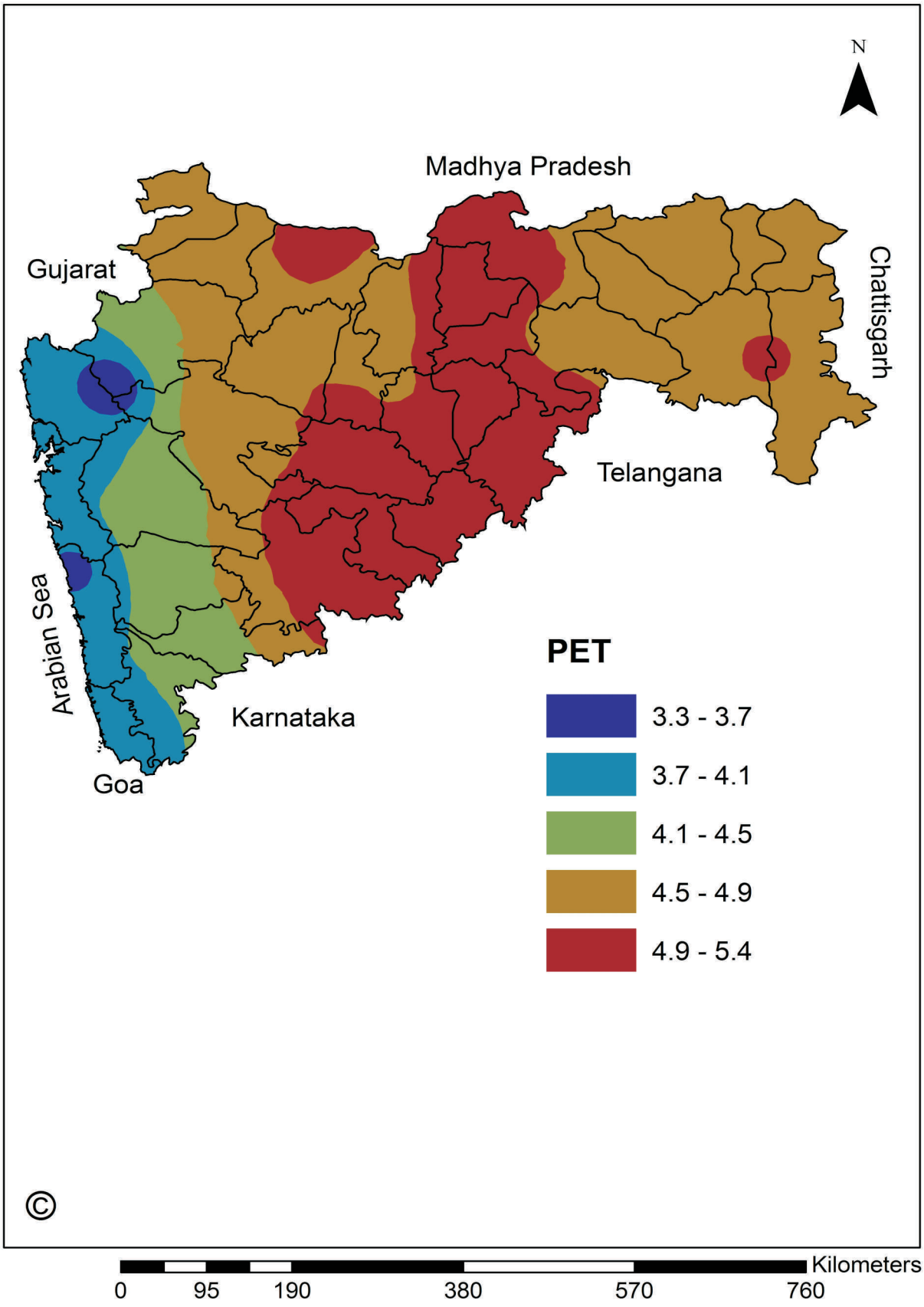

Fig. 74: Southwest monsoon season potential evapotranspiration (mm/day) over Maharashtra

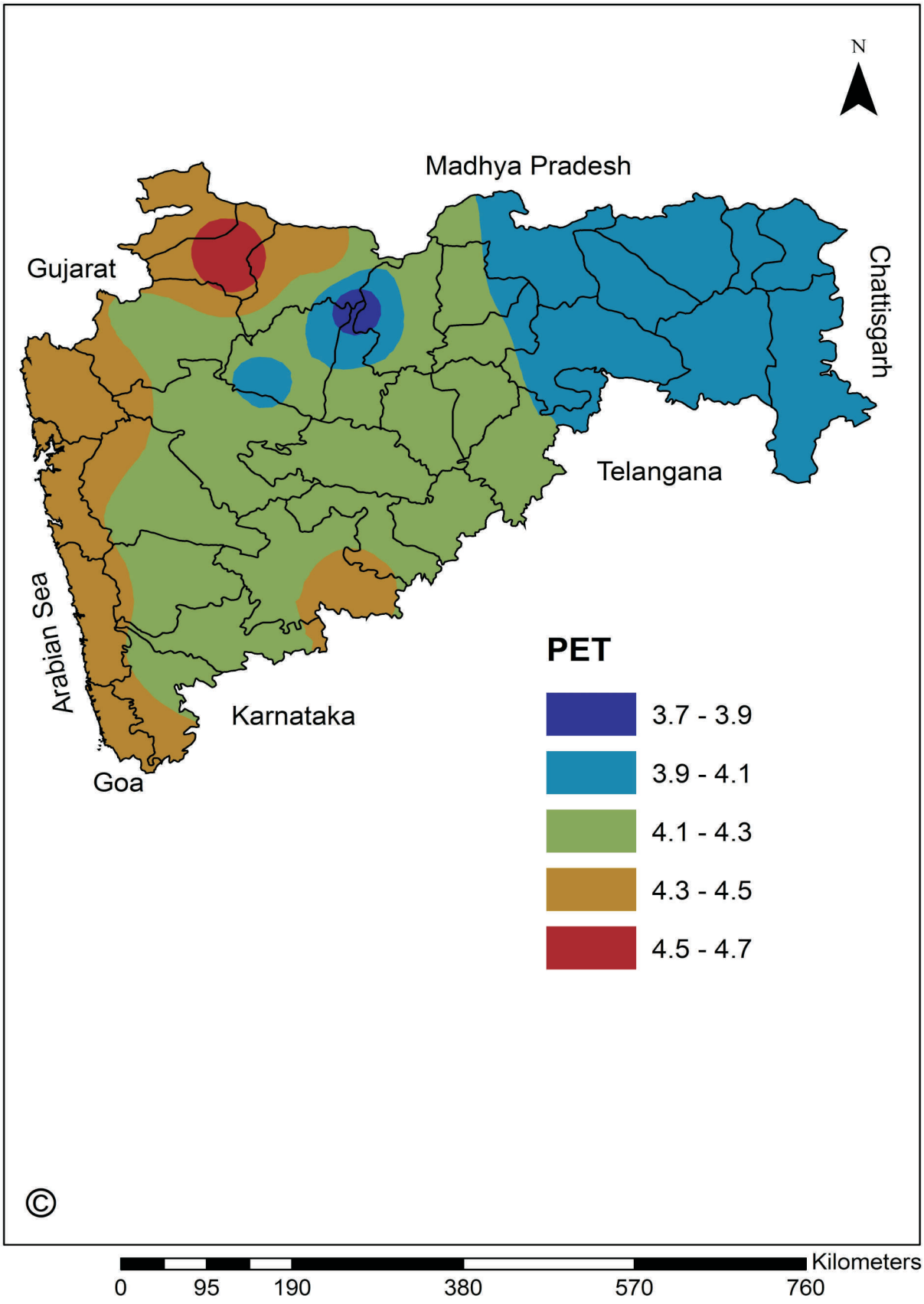

Fig. 75: Post monsoon (PM) season potential evapotranspiration (mm/day) over Maharashtra

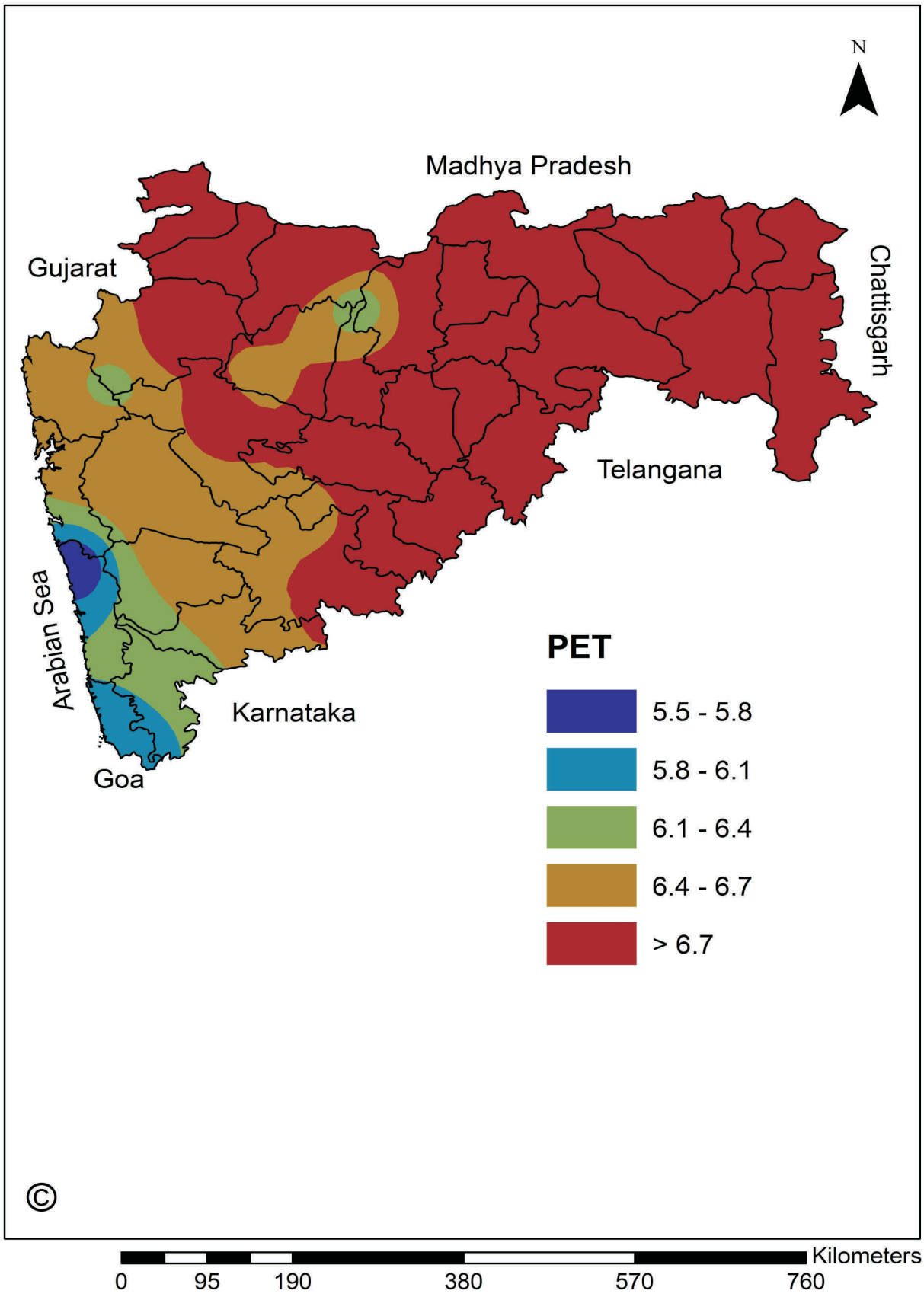

Fig. 76: Summer season potential evapotranspiration (mm/day) over Maharashtra

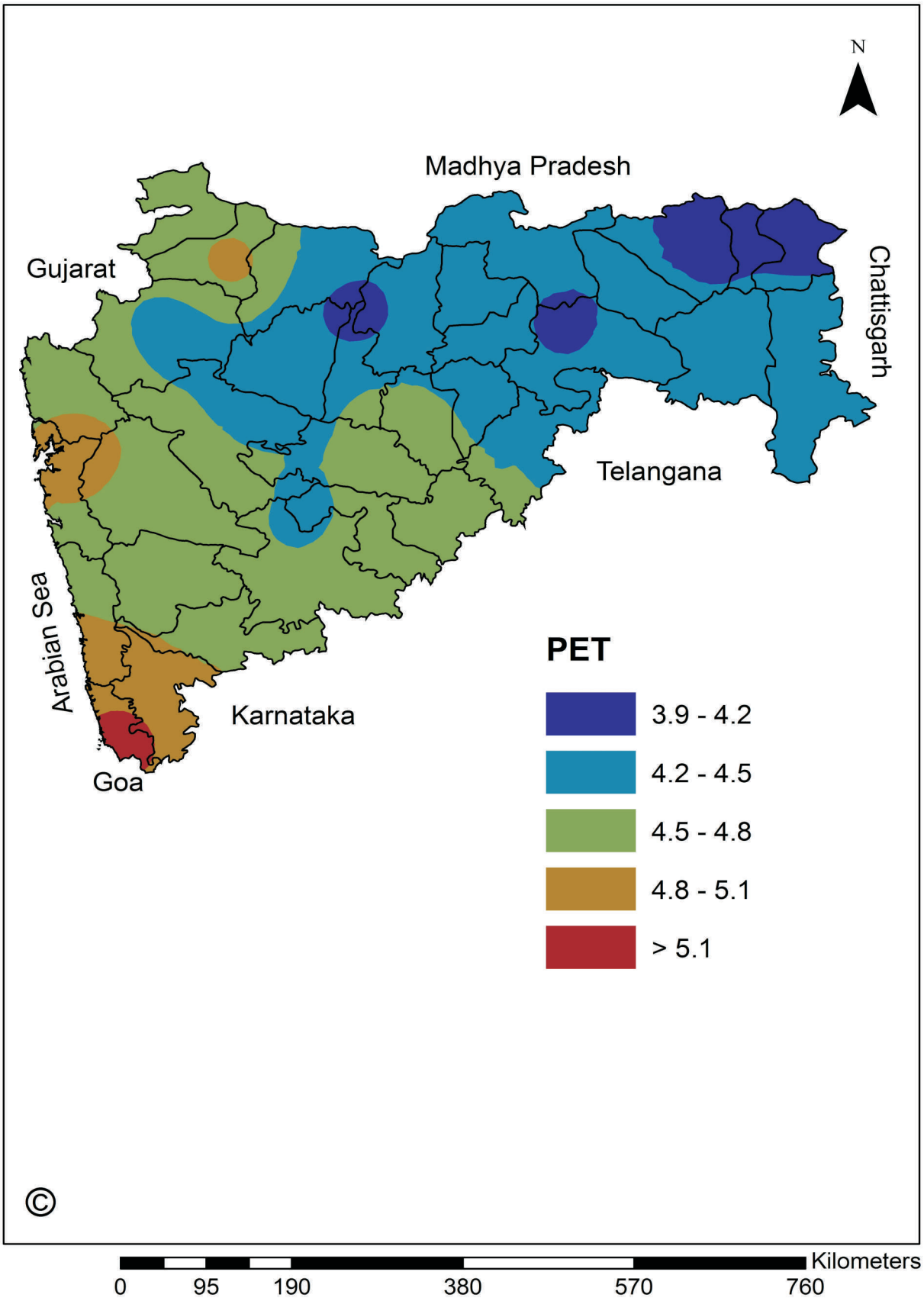

Fig. 77: Winter season potential evapotranspiration (mm/day) over Maharashtra

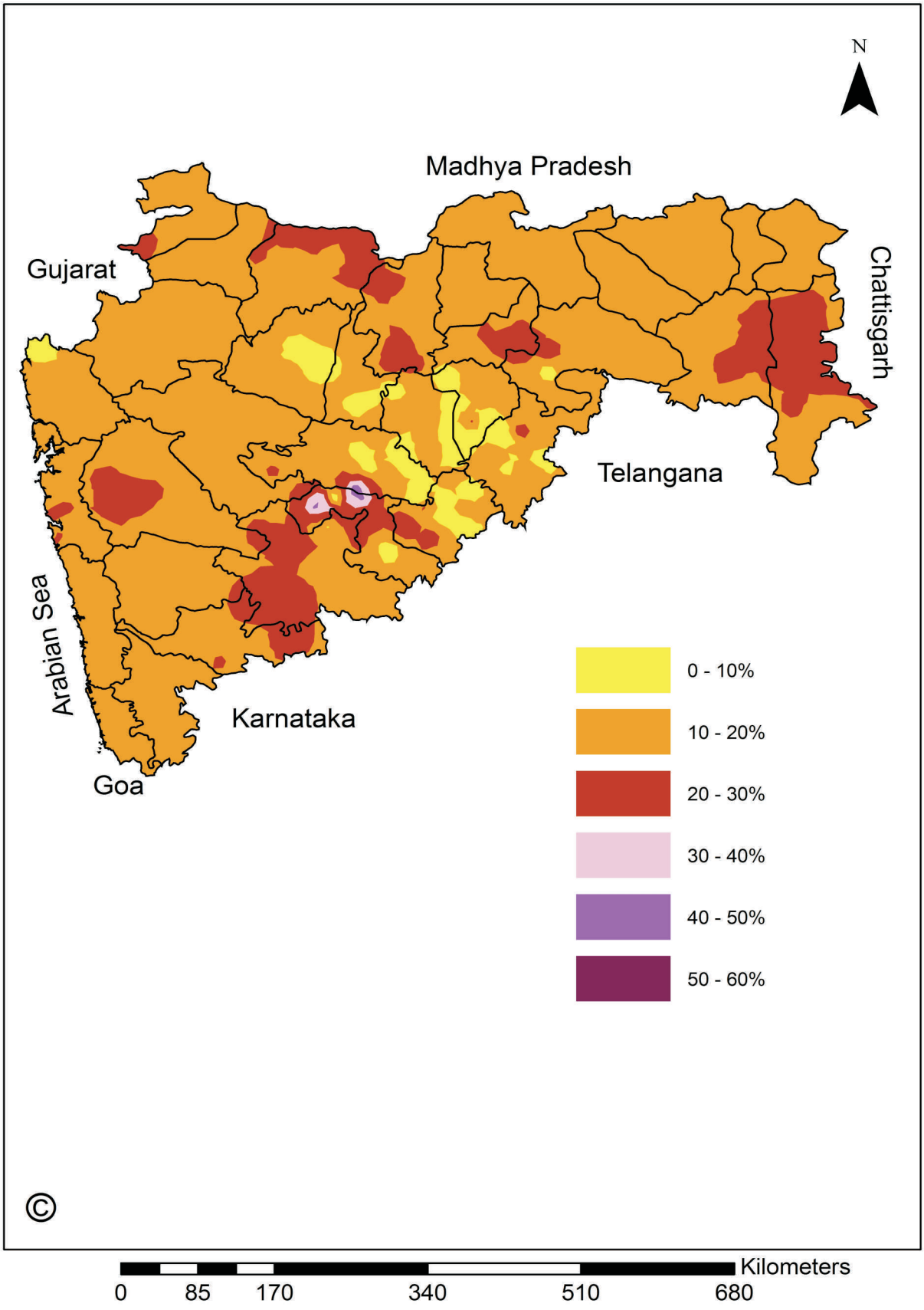

Fig. 78: Probability of occurrence of moderate drought in Maharashtra

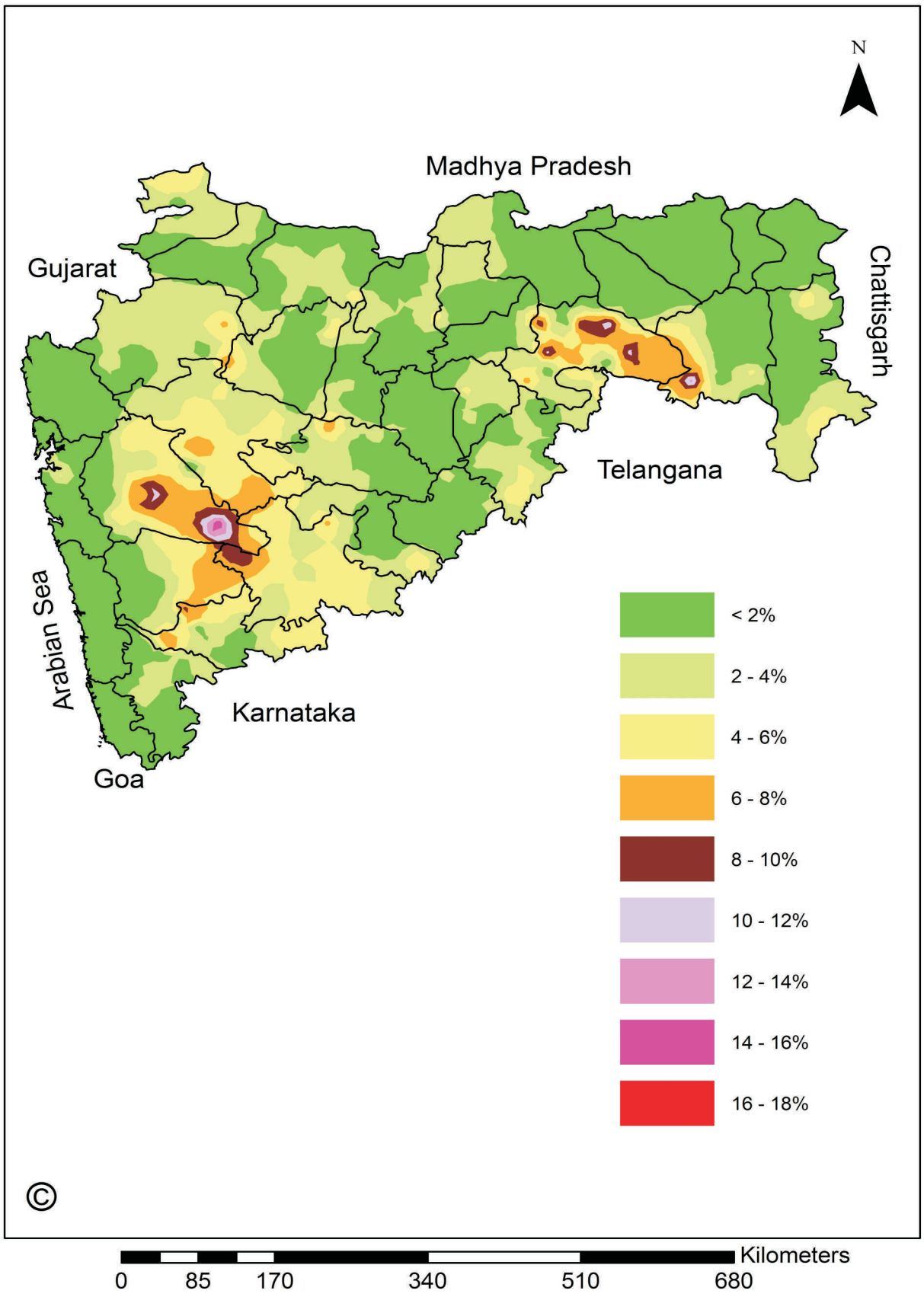

Fig. 79 : Probability for the occurrence of severe drought in Maharashtra

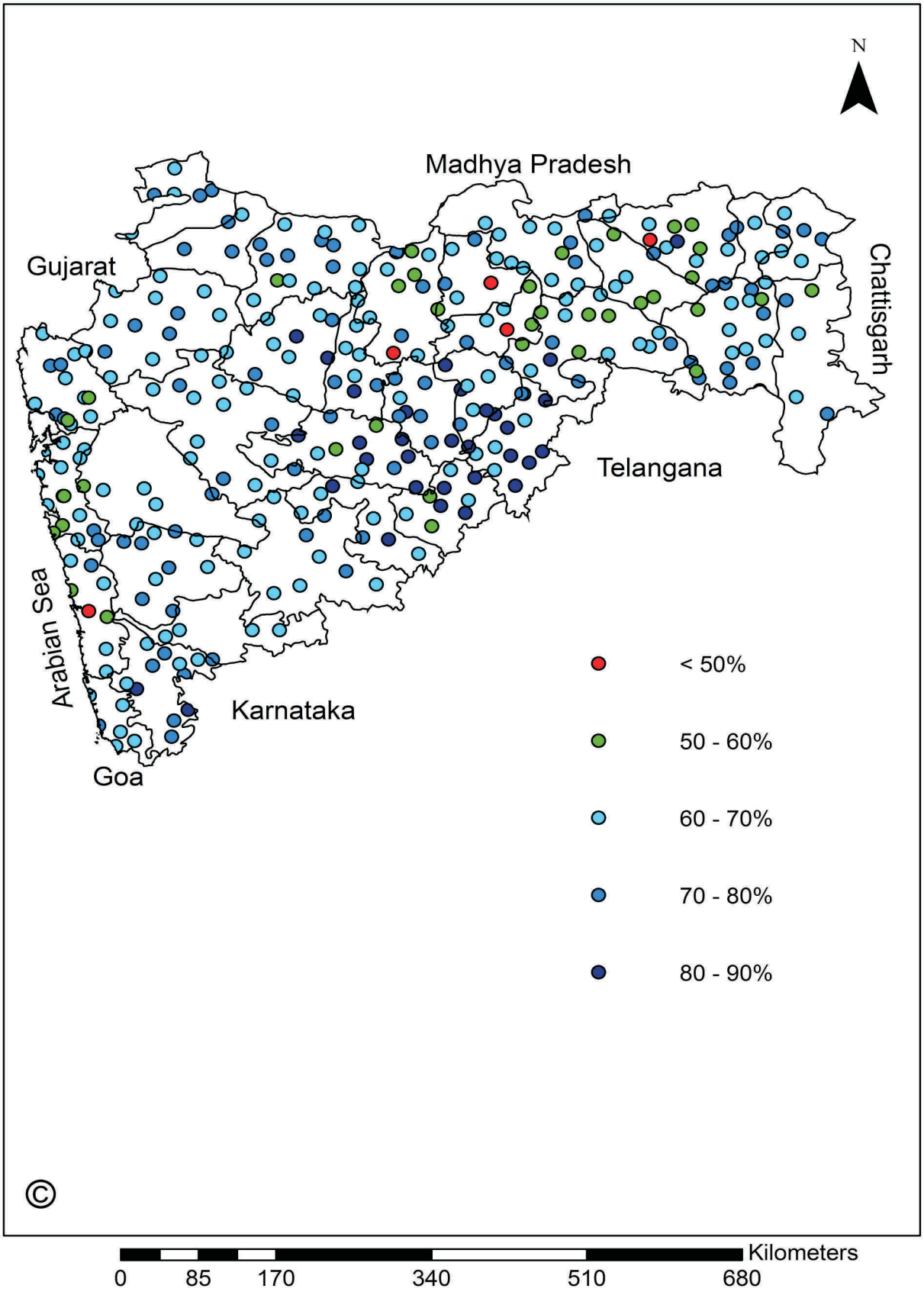

Fig. 80 a : Probability of experiencing near normal conditions based on annual basis (SPI between -0.99 to +0.99)

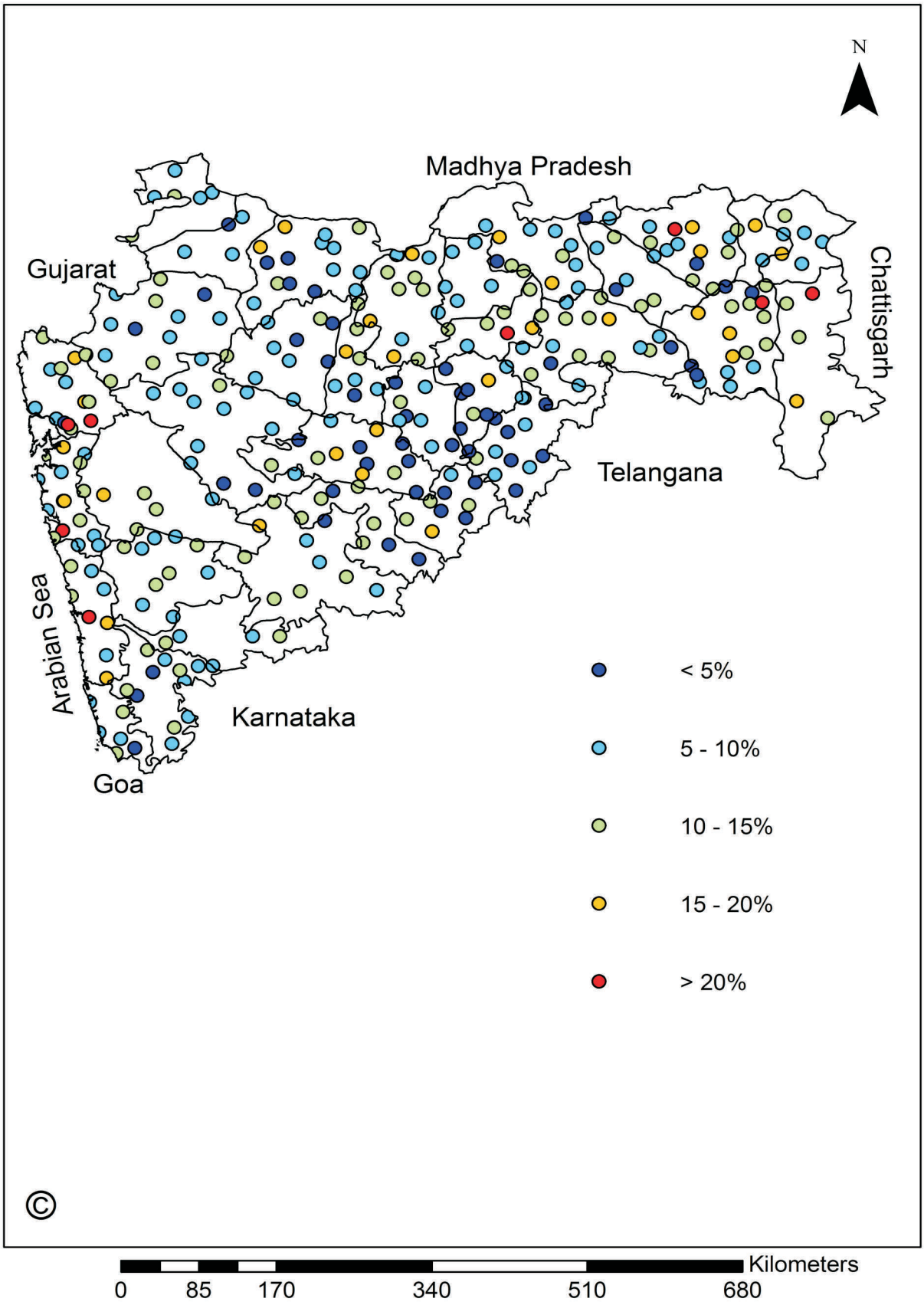

Fig. 80 b : Probability of experiencing moderately dry conditions based on annual basis (SPI between -1.00 to -1.49)

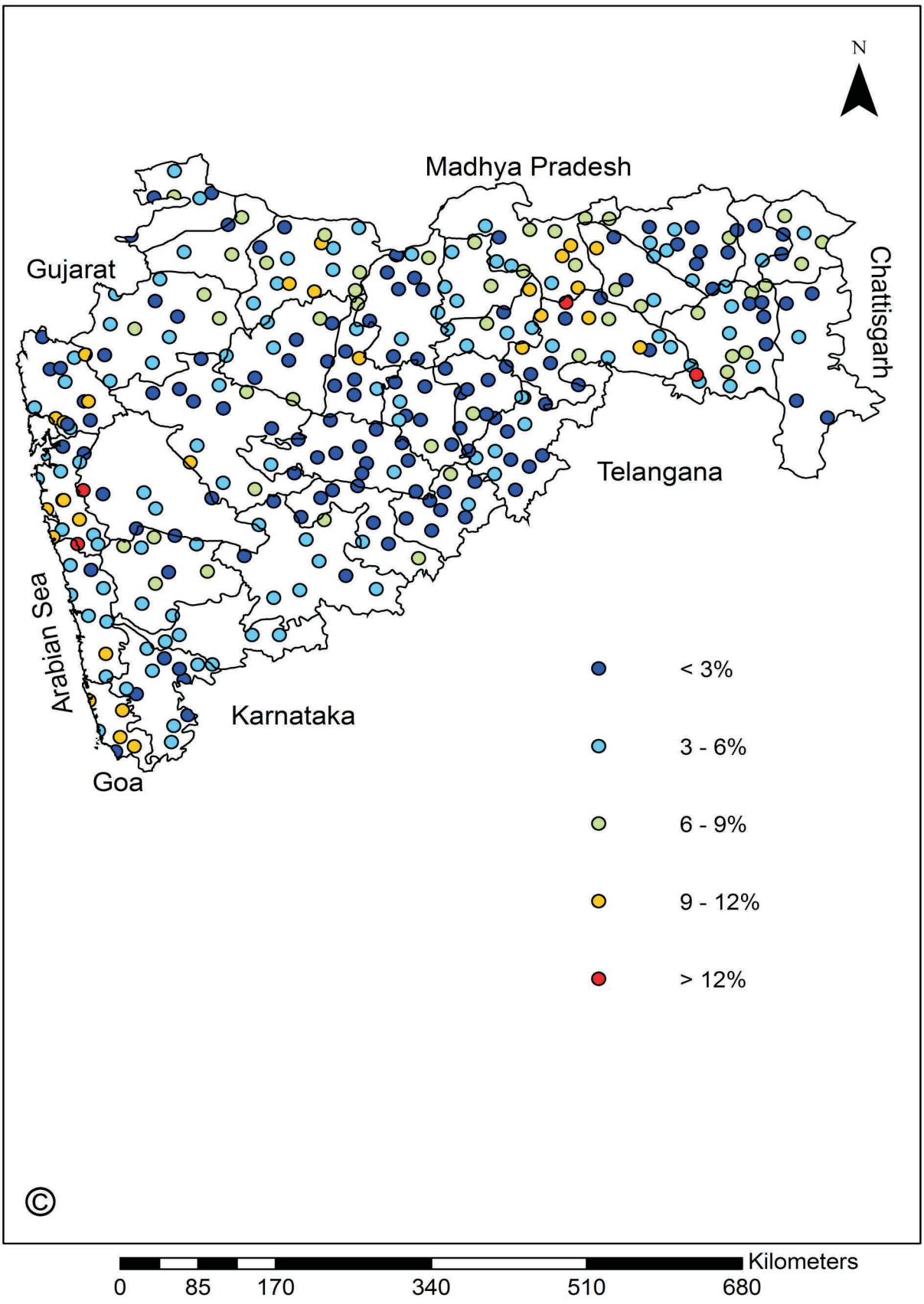

Fig. 80 c : Probability of experiencing severely dry conditions based on annual basis (SPI between -1.5 to -1.99)

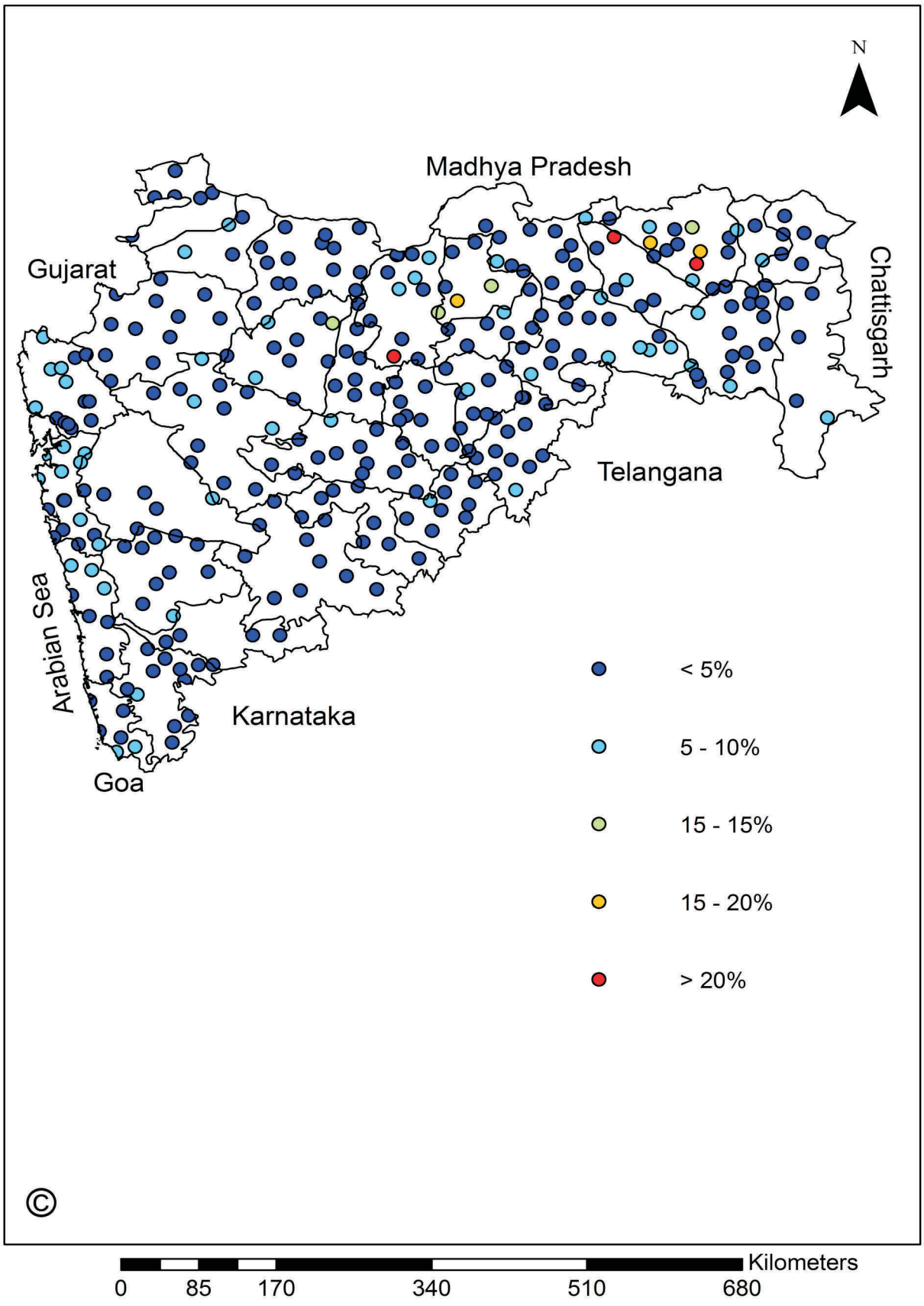

Fig. 80 d : Probability of experiencing extremely dry conditions based on annual basis (SPI less than -2.0)

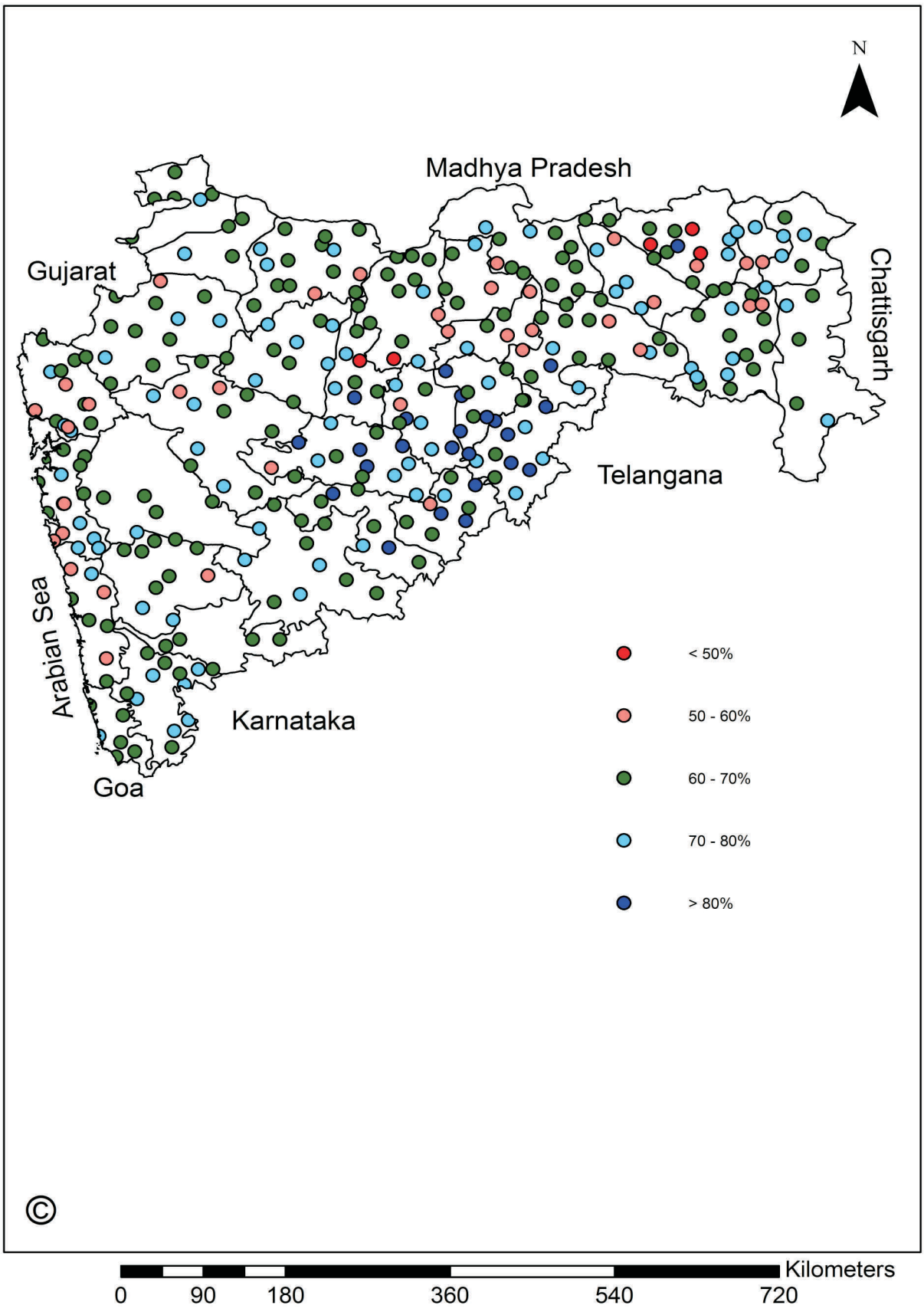

Fig. 81 a : Probability of near normal dry rainfall during Southwest monsoon (SPI between -0.99 to +0.99) in Maharashtra

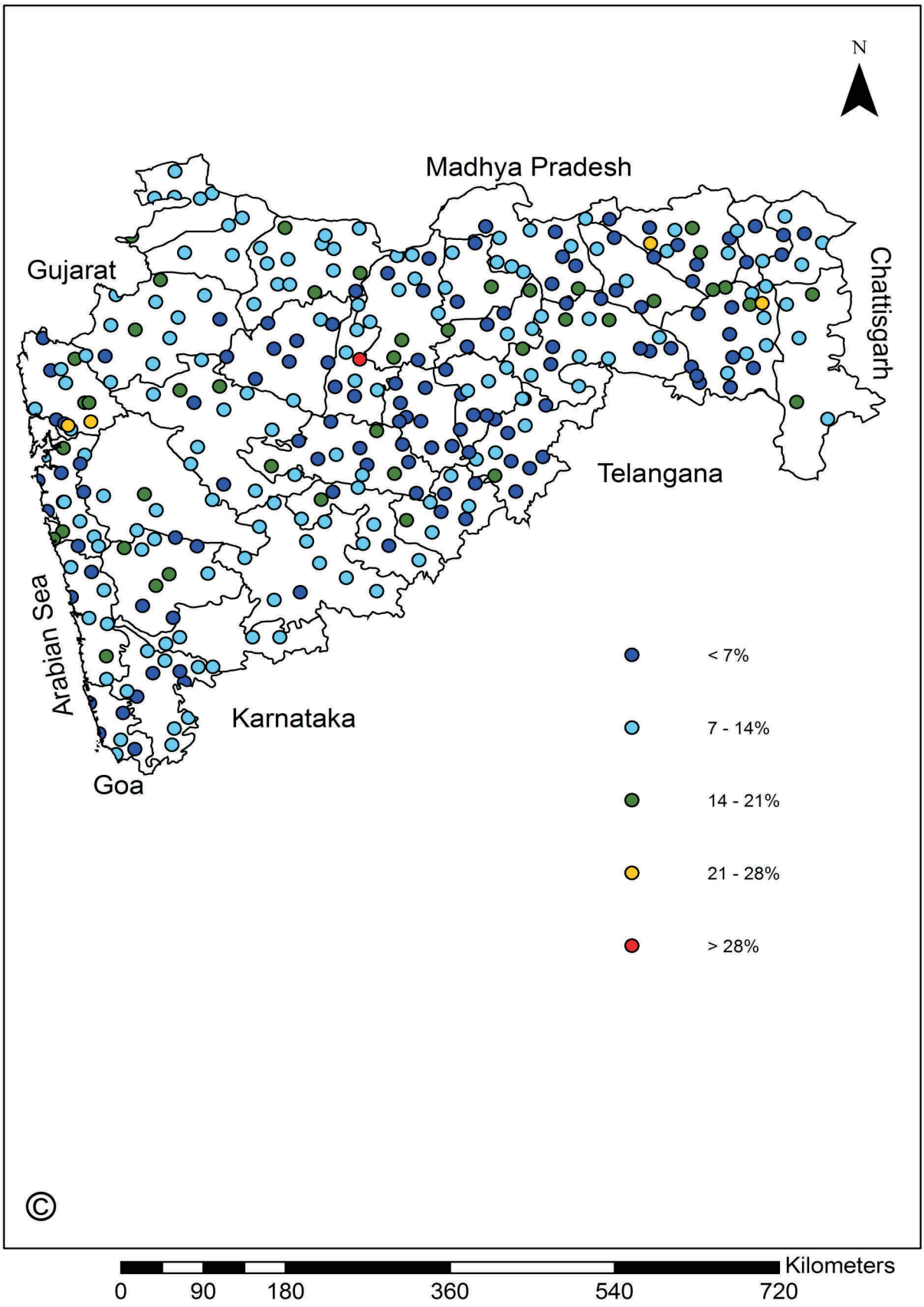

Fig. 81 b: Probability of moderately dry rainfall during Southwest monsoon (SPI between -1.00 to -1.49) in Maharashtra

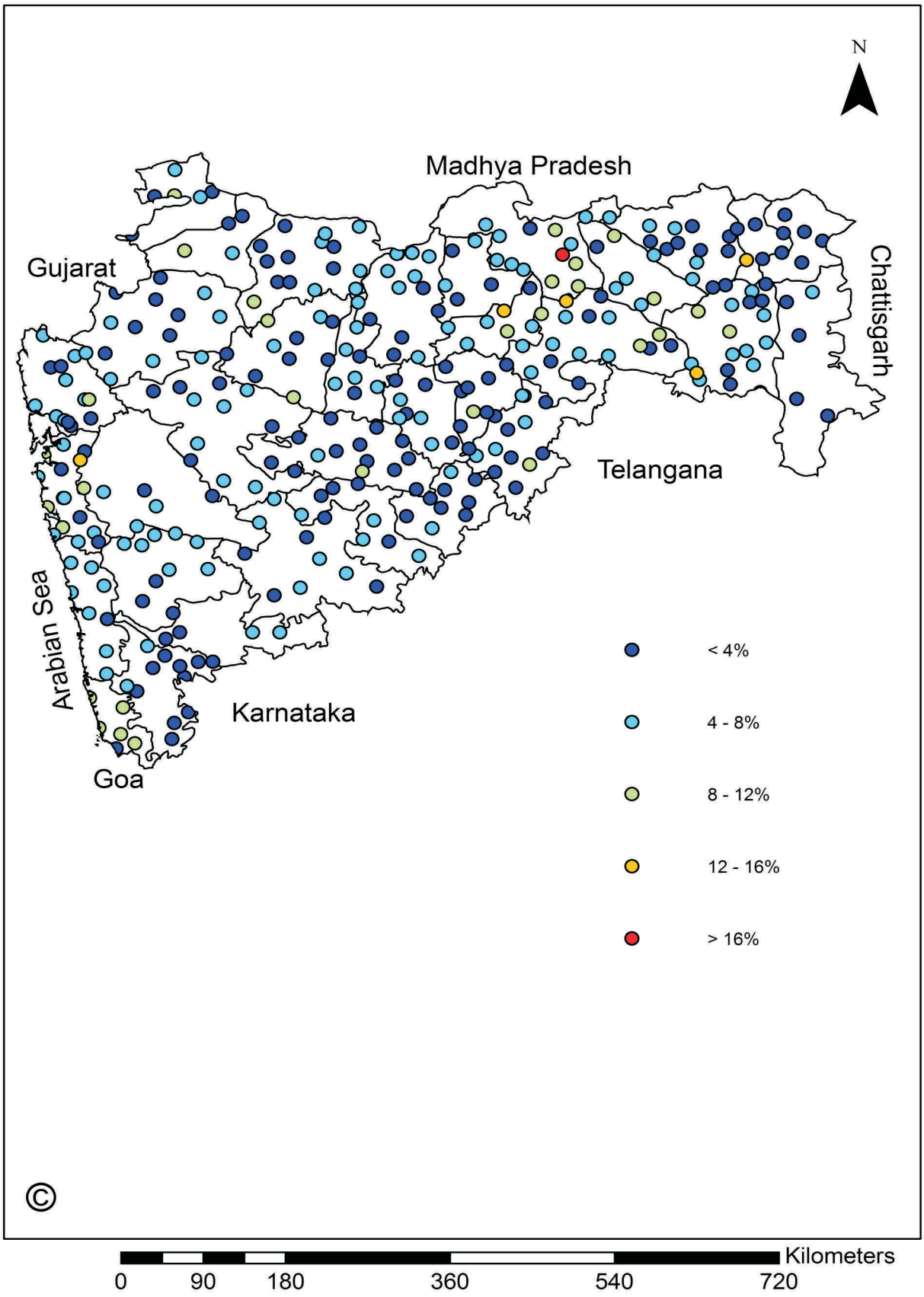

Fig. 81 c: Probability of severely rainfall during Southwest monsoon (SPI between -1.5 to -1.99) in Maharashtra

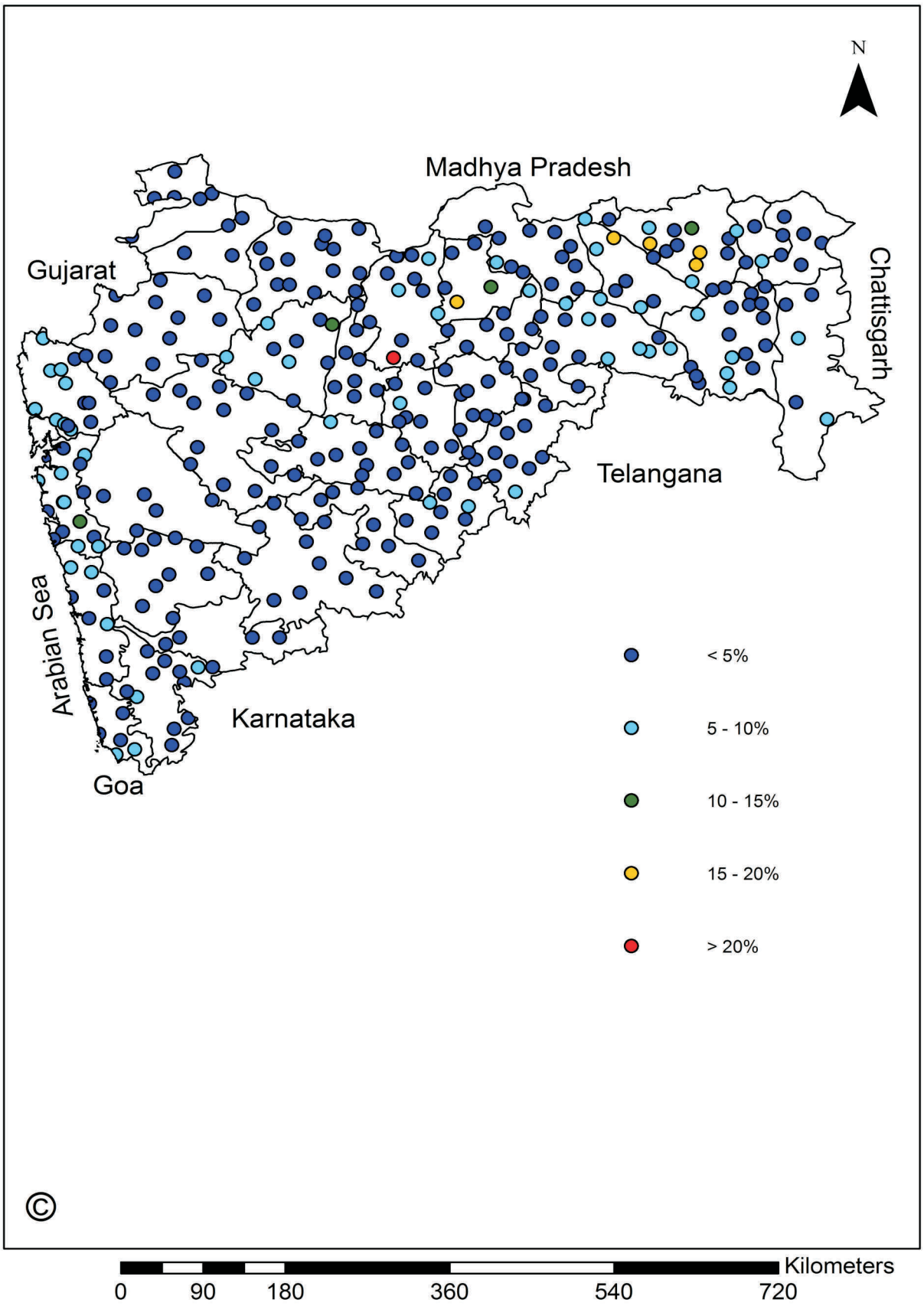

Fig. 81 d: Probability of extremely dry rainfall during Southwest monsoon (SPI less than -2.0) in Maharashtra

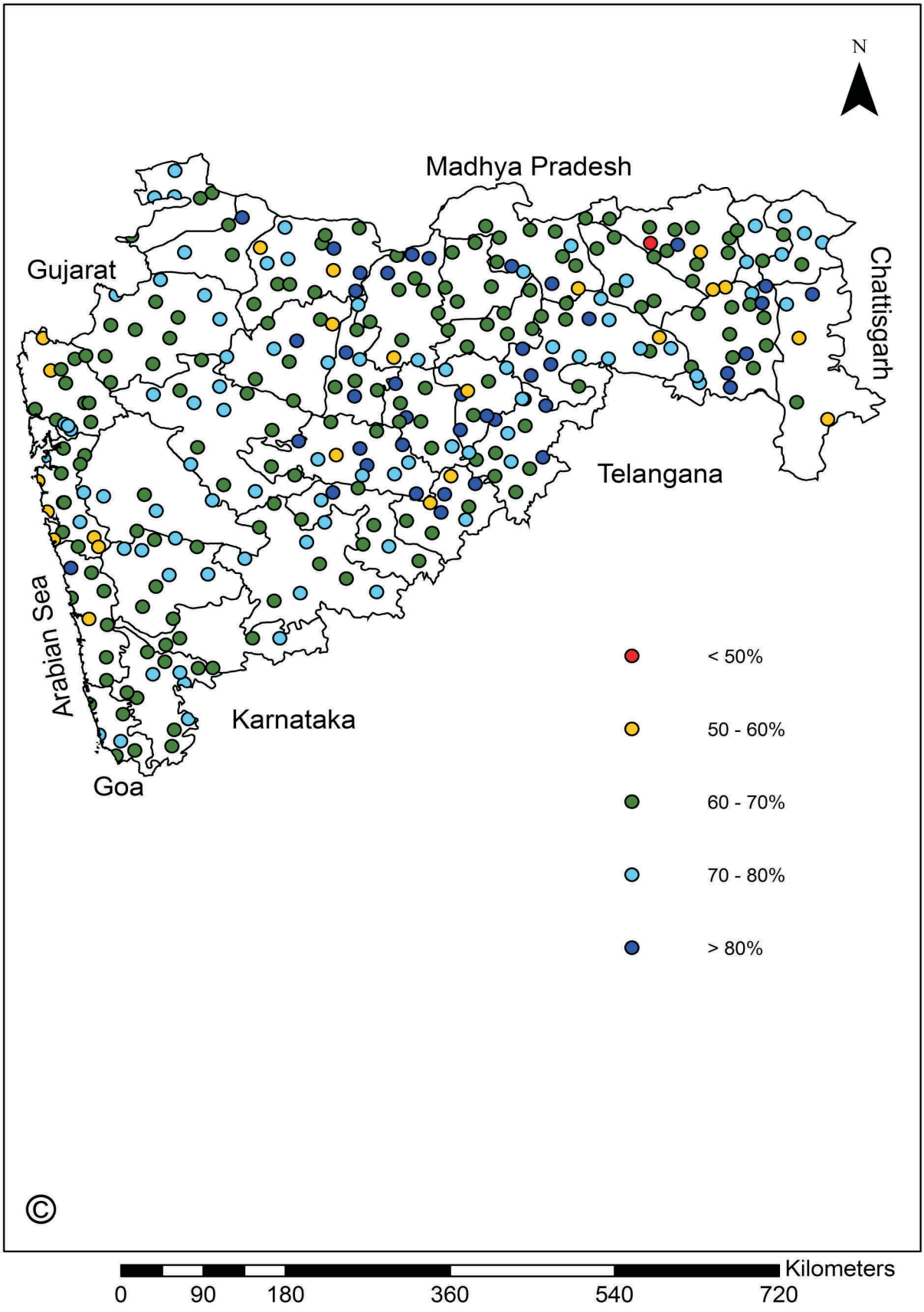

Fig. 82 a: Probability of near normal dry rainfall during Post monsoon (SPI between -0.99 to +0.99) in Maharashtra

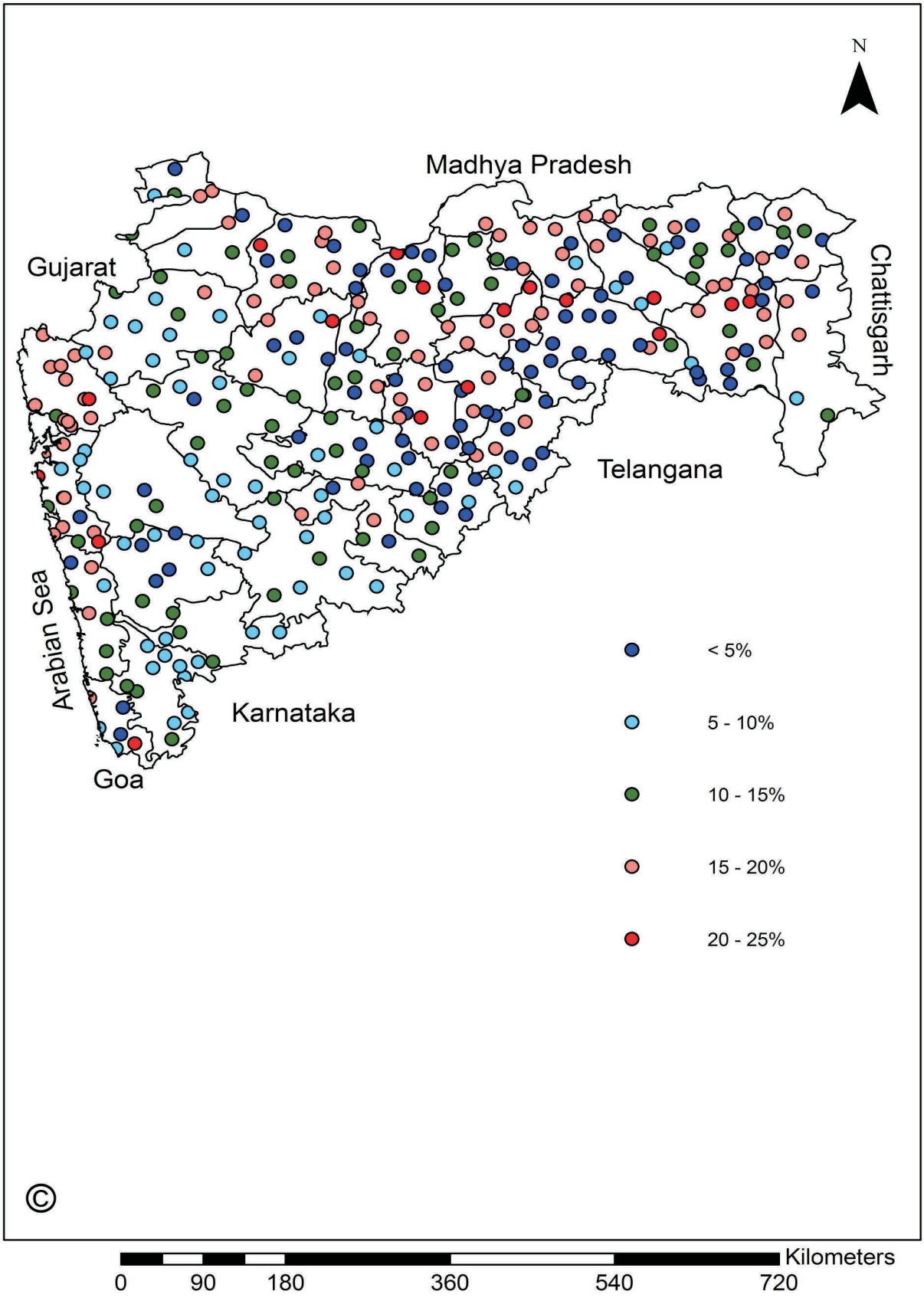

Fig. 82 b: Probability of moderately dry rainfall during Northeast monsoon (SPI between -1.00 to -1.49) in Maharashtra

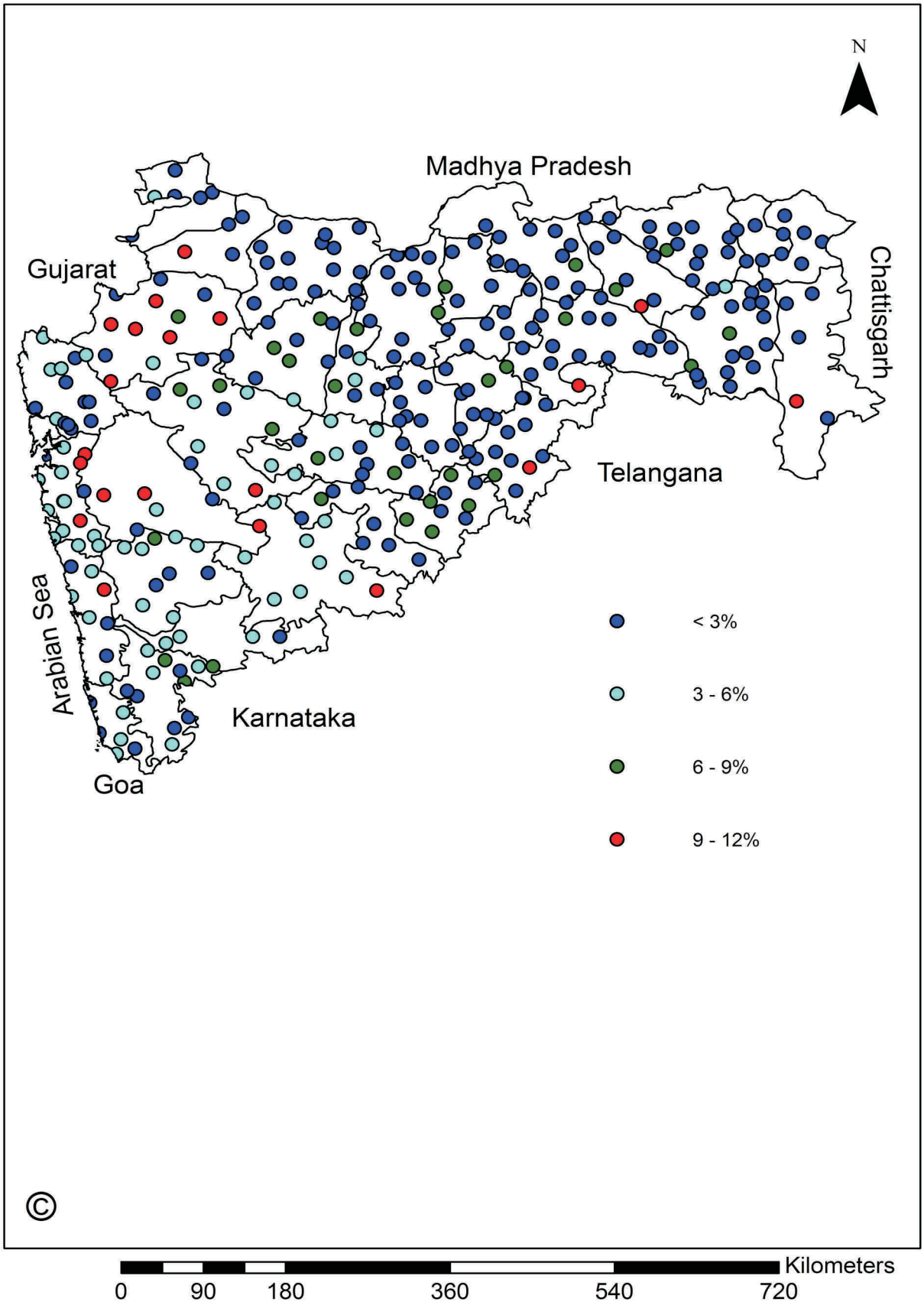

Fig. 82 c: Probability of severely rainfall during Northeast monsoon (SPI between -1.5 to -1.99) in Maharashtra

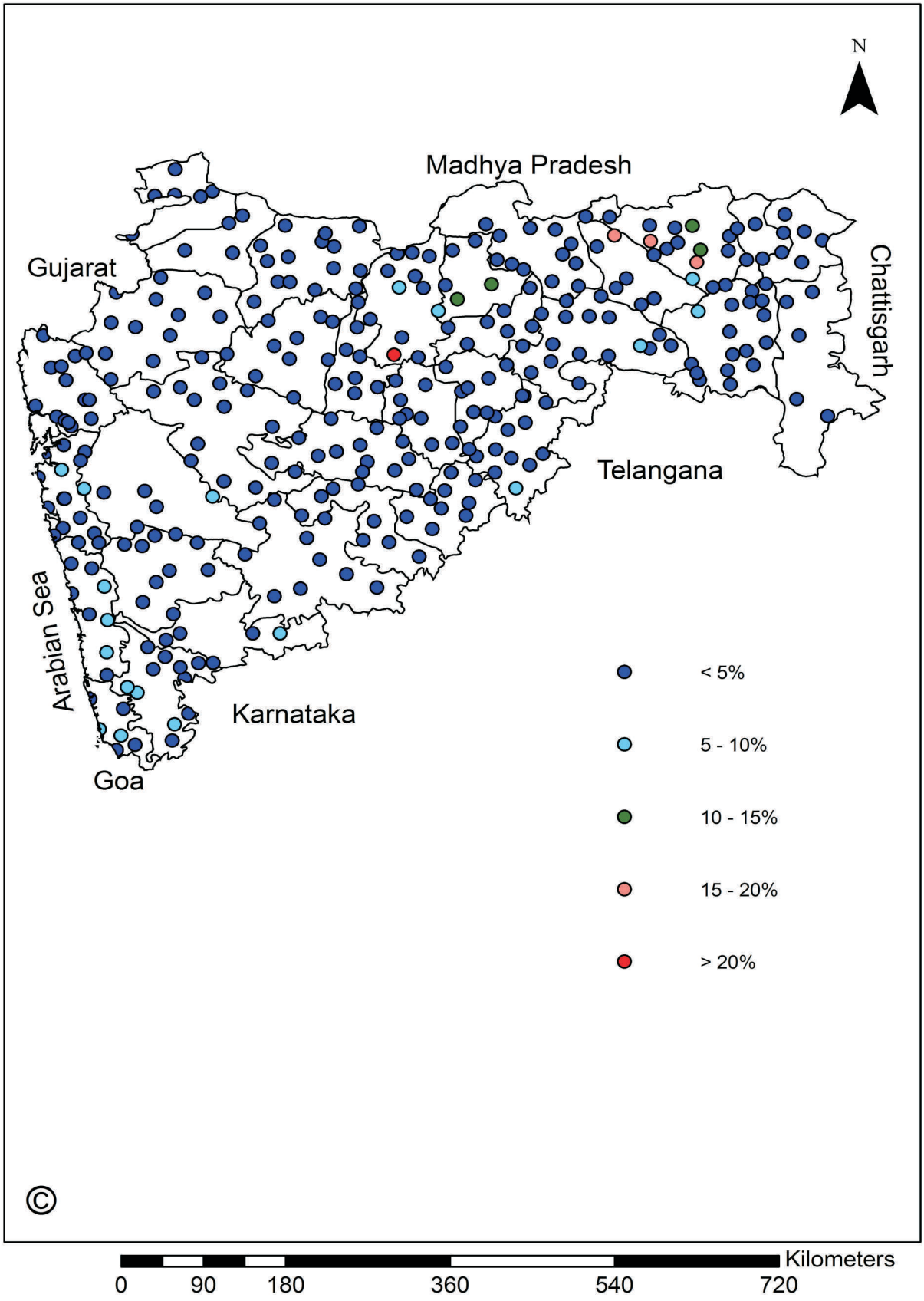

Fig. 82 d: Probability of extremely dry rainfall during Northeast monsoon (SPI less than -2.0) in Maharashtra

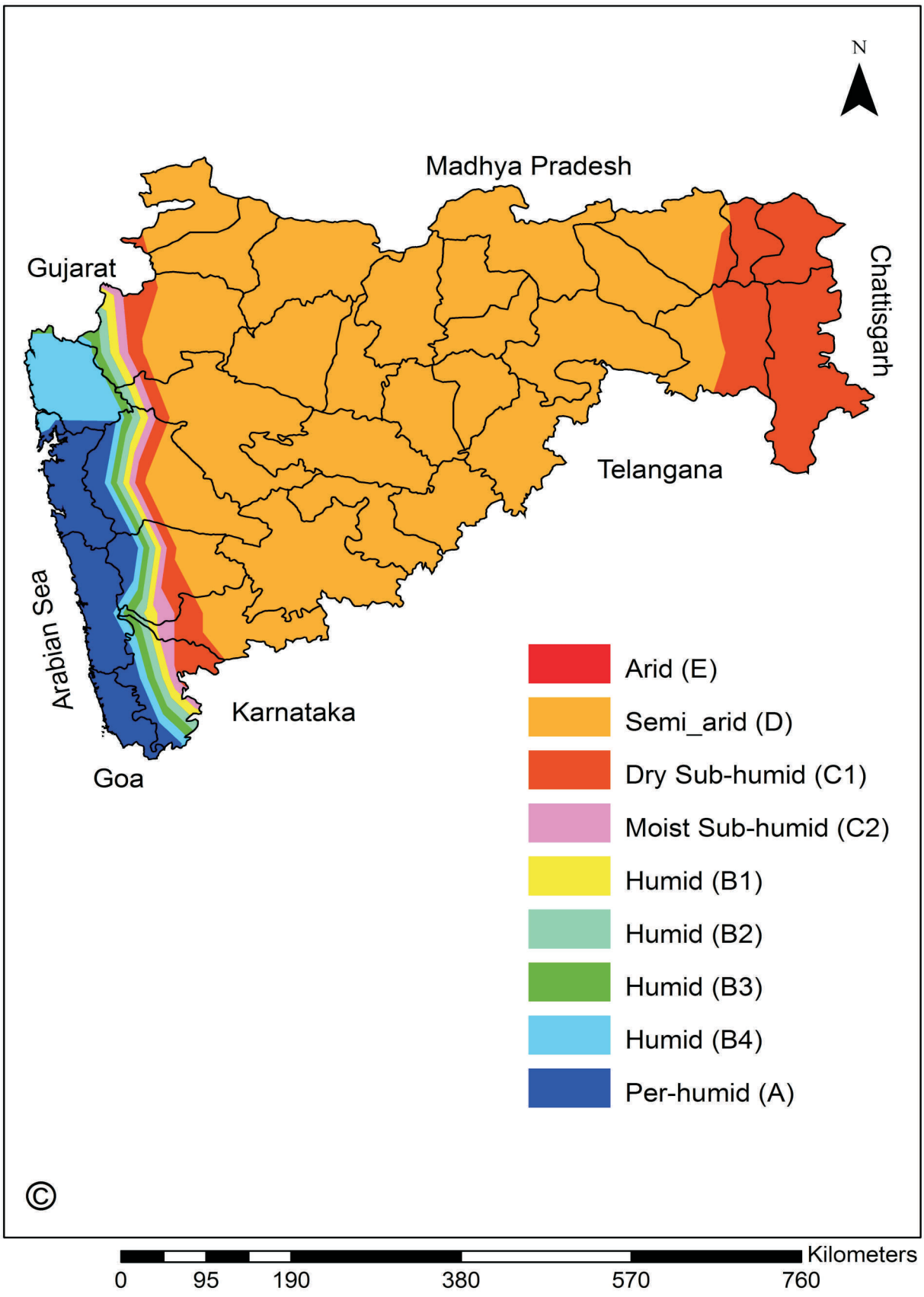

Fig. 83: Regions having different climatic types

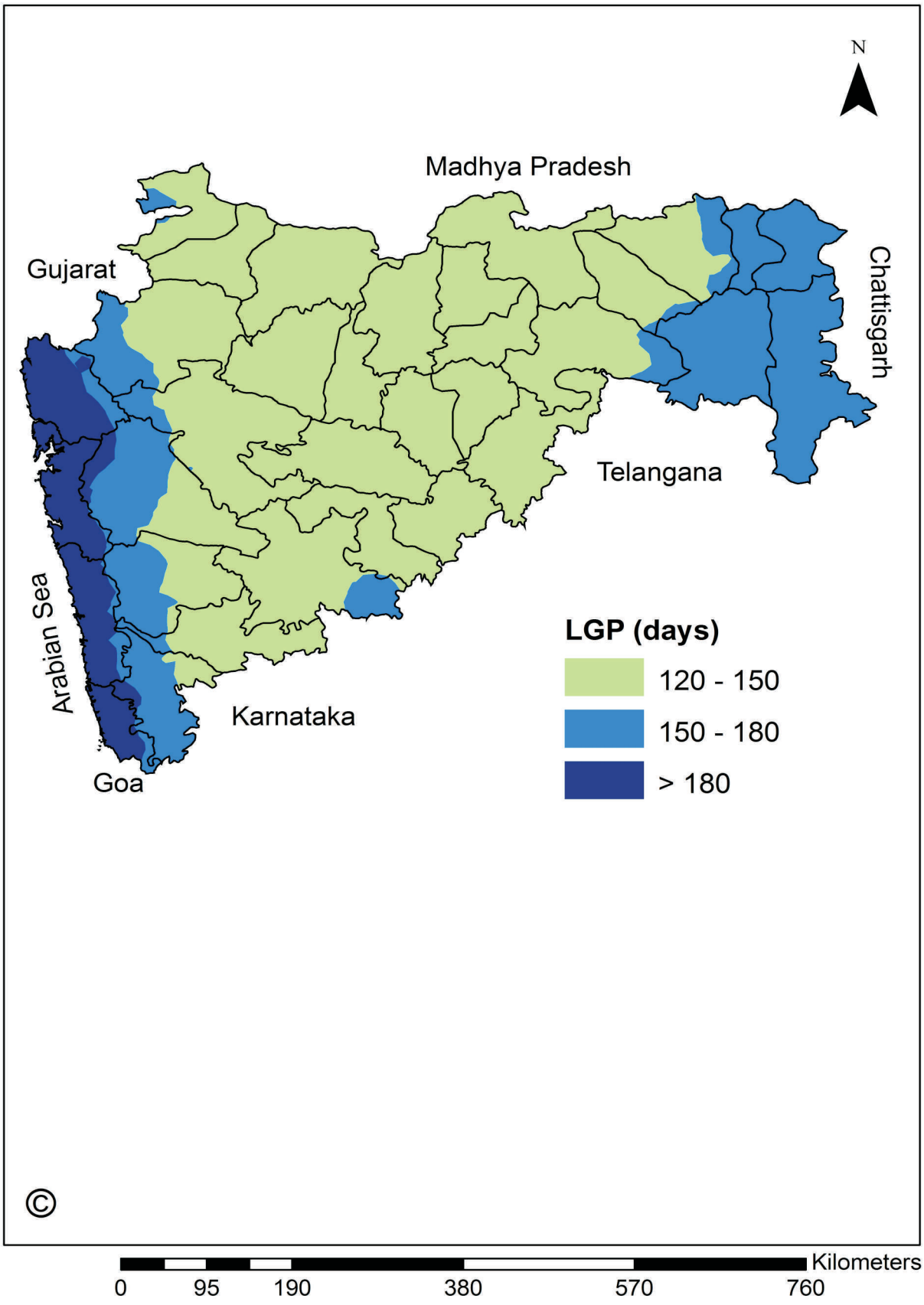

Fig. 84: Length of growing period (LGP) days in Maharashtra

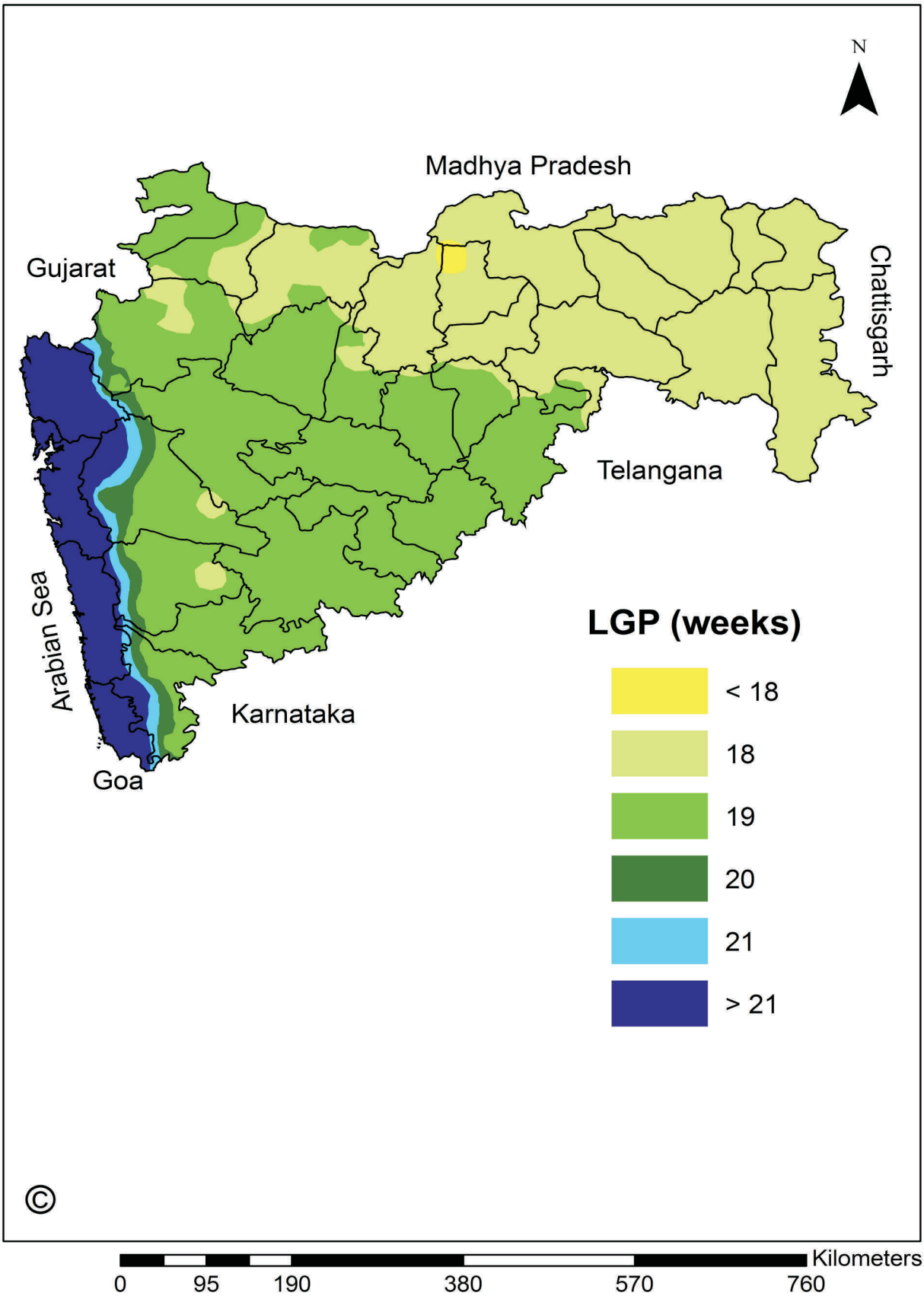

Fig. 85 a: LGP (weeks) soils having water holding capacity of 50 mm in Maharashtra

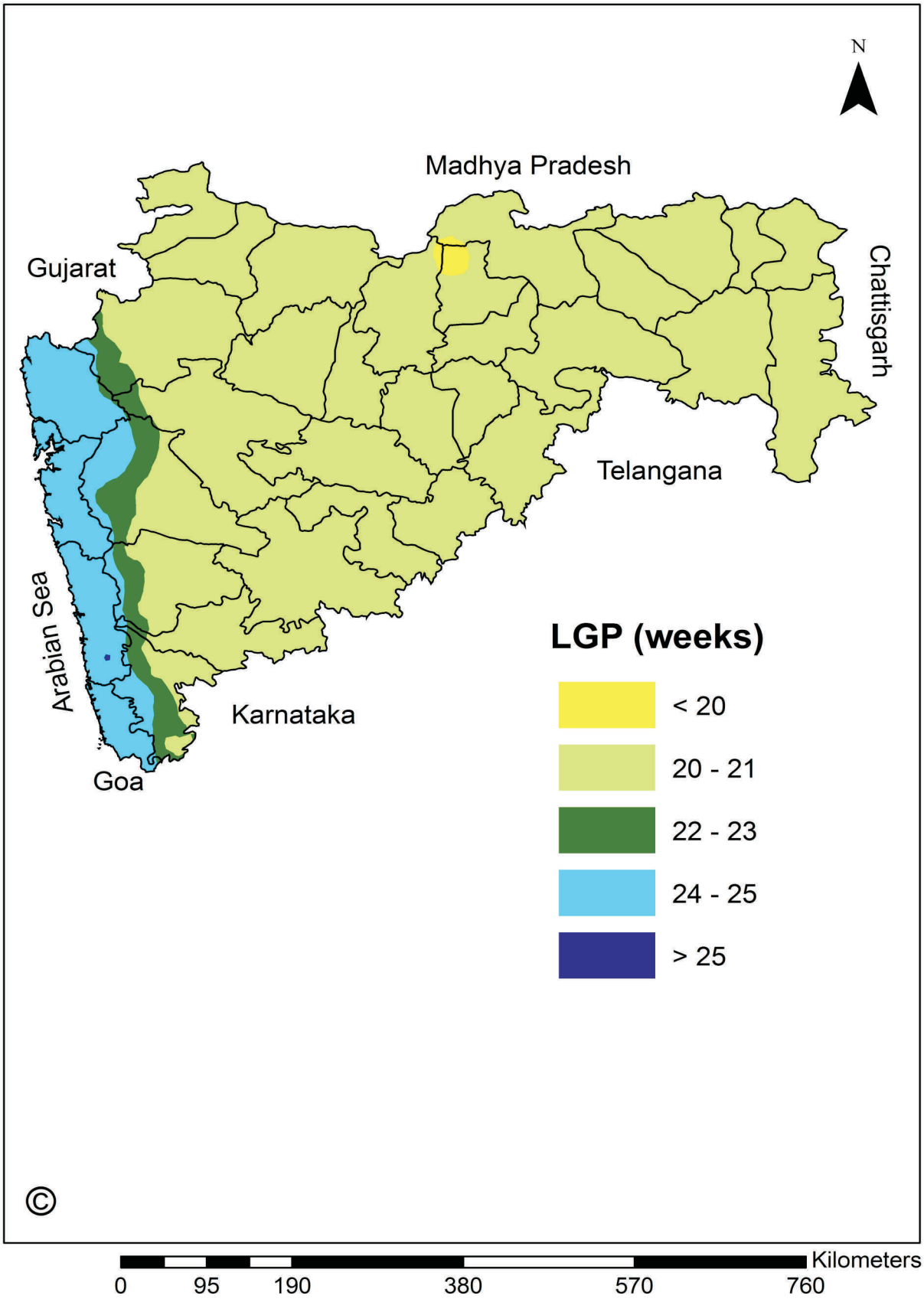

Fig. 85 b: LGP (weeks) soils having water holding capacity of 100 mm in Maharashtra

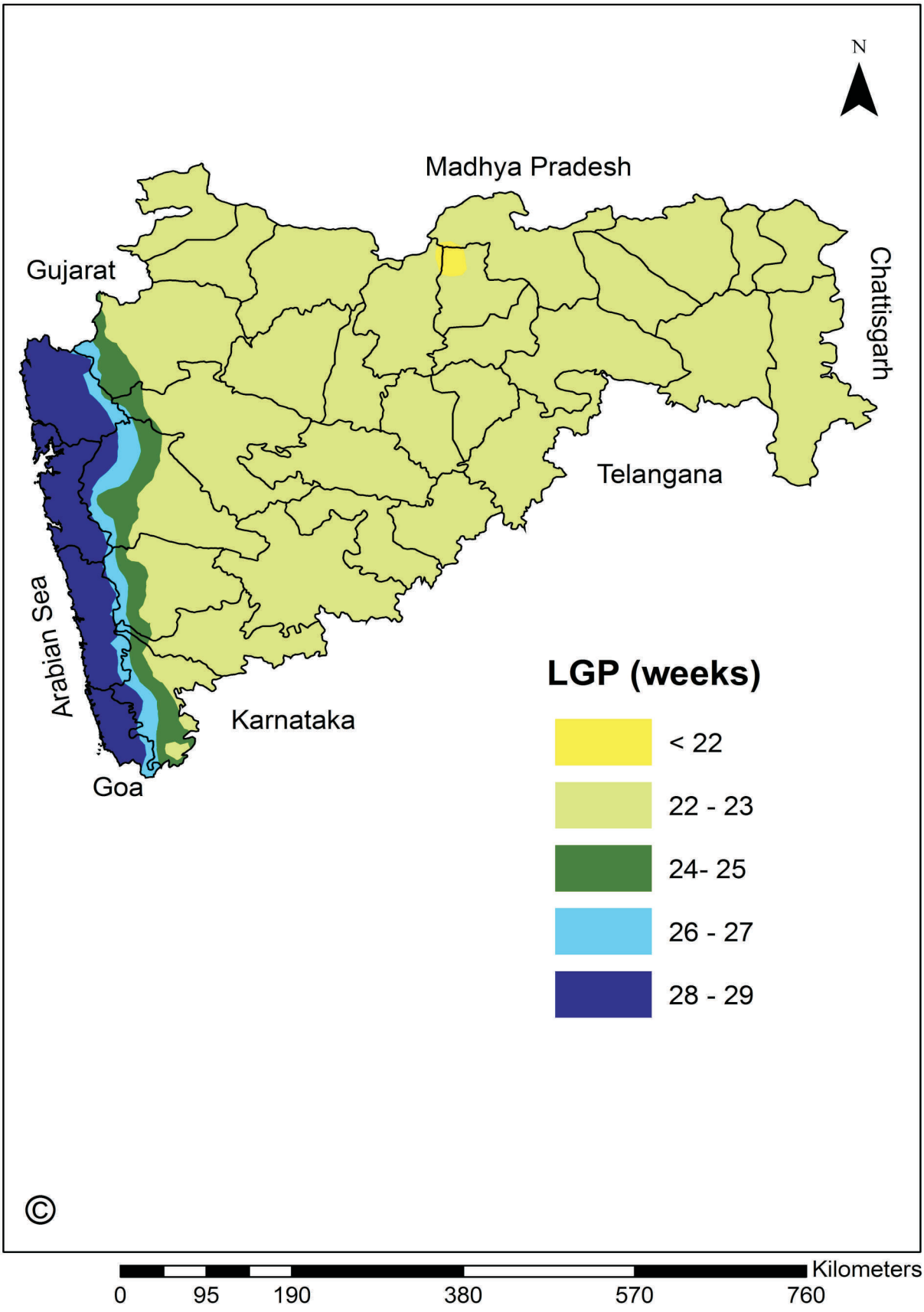

Fig. 85 c: LGP (weeks) soils having water holding capacity of 150 mm in Maharashtra

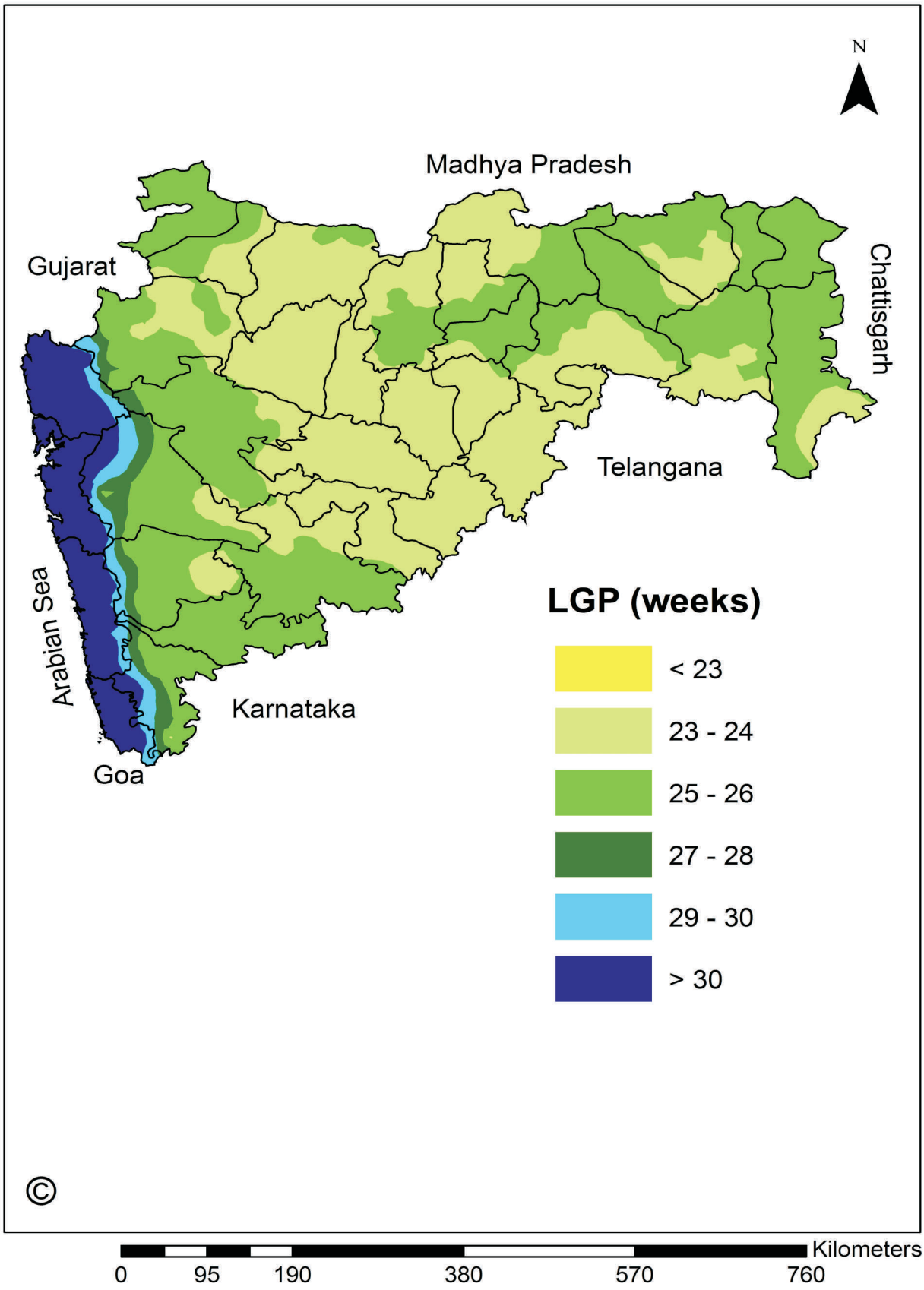

Fig. 85 d: LGP (weeks) soils having water holding capacity of 200 mm in Maharashtra

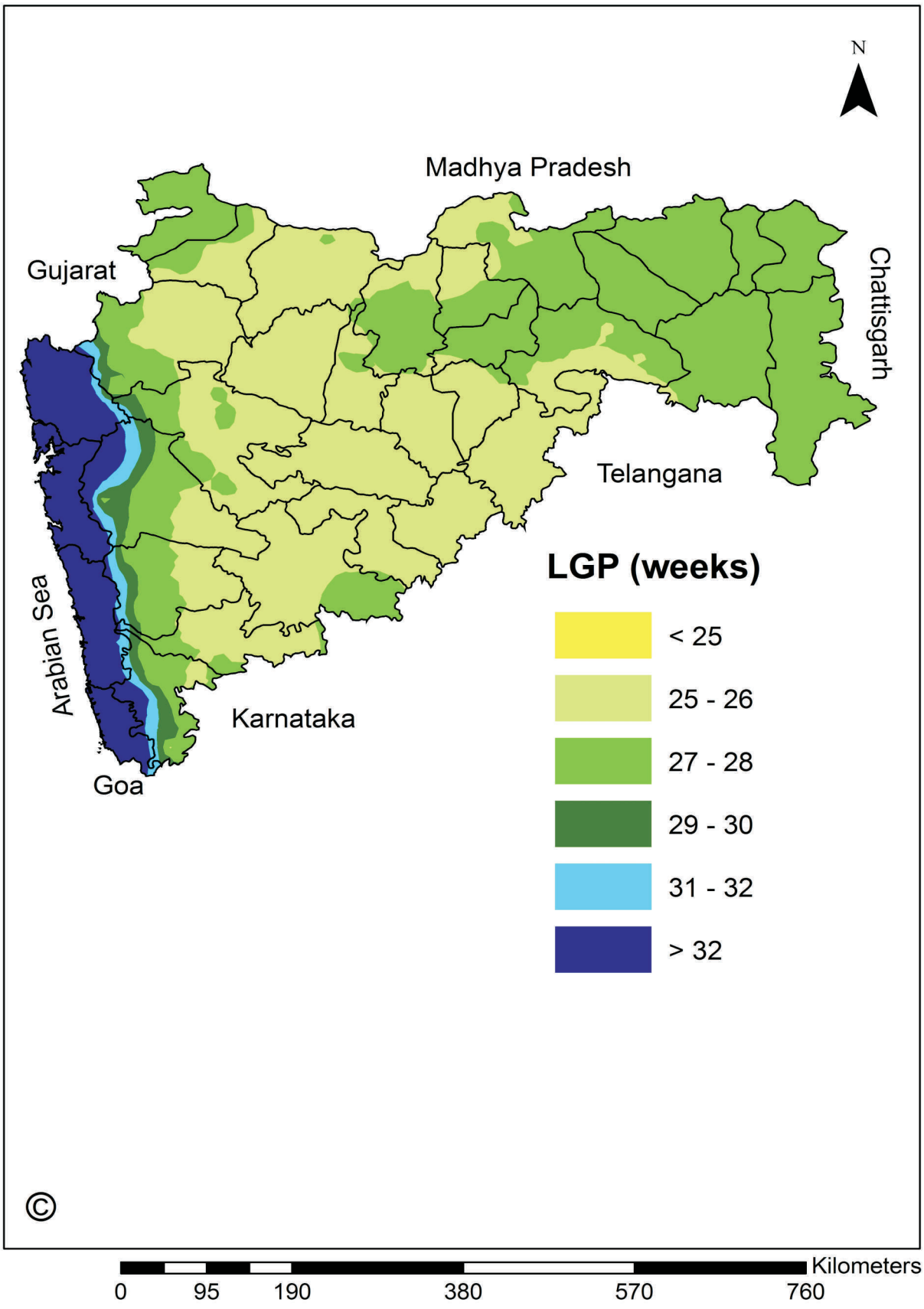

Fig. 85 e: LGP (weeks) soils having water holding capacity of 250 mm in Maharashtra

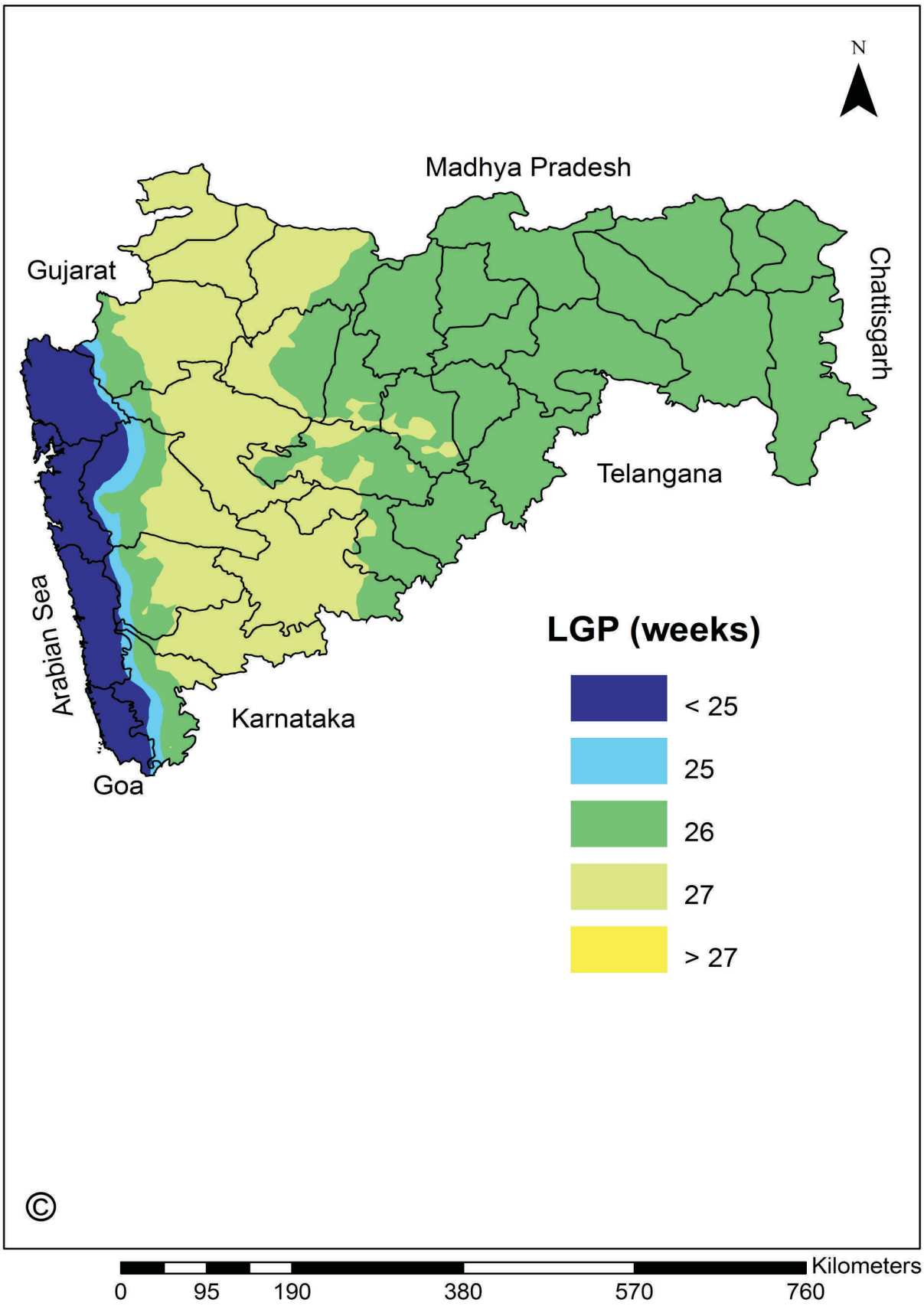

Fig.86 a: Commencement of growing season (SMW) for soils having water holding capacity of 50 mm in Maharashtra

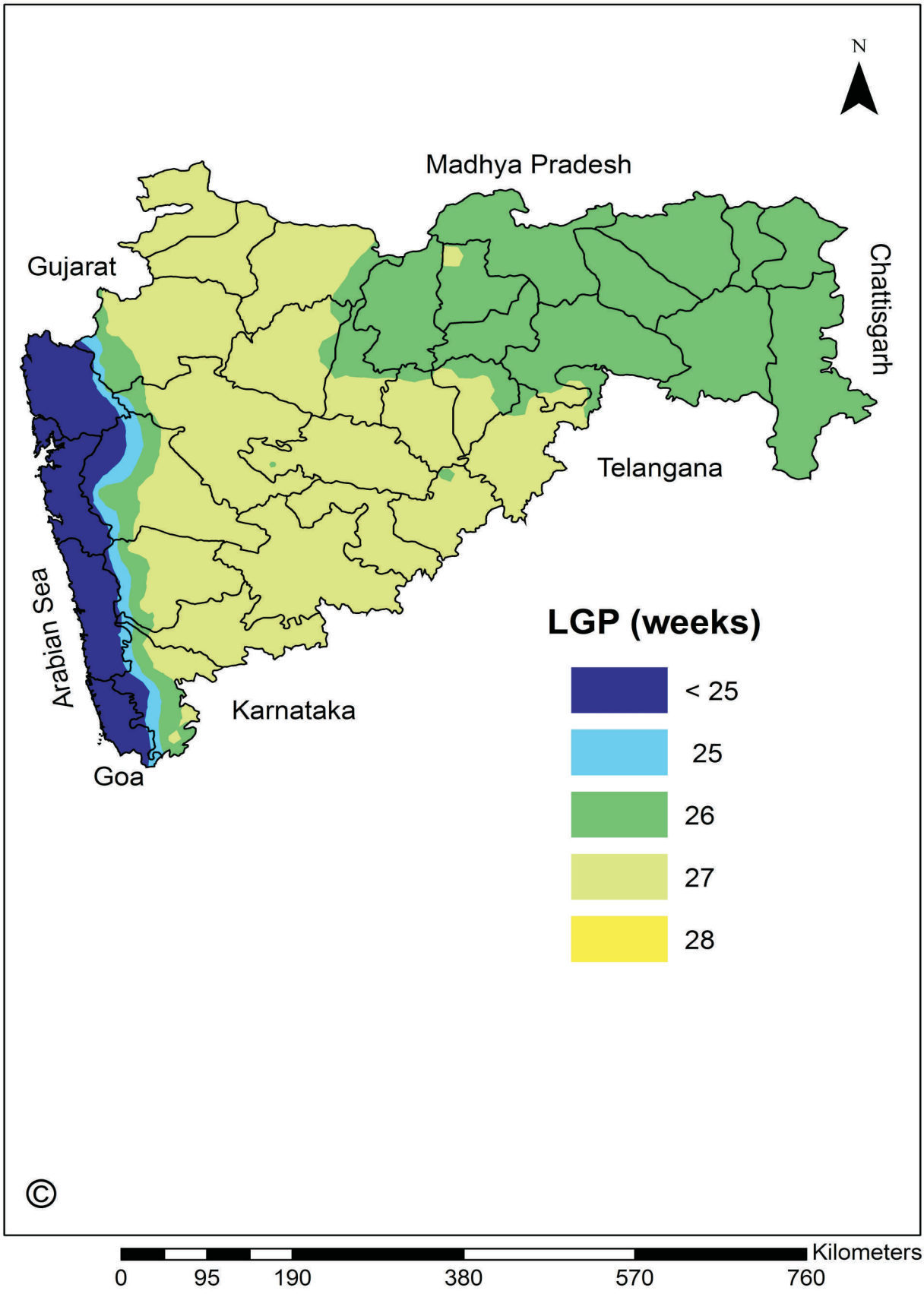

Fig. 86 b: Commencement of growing season (SMW) for soils having water holding capacity of 100 mm in Maharashtra

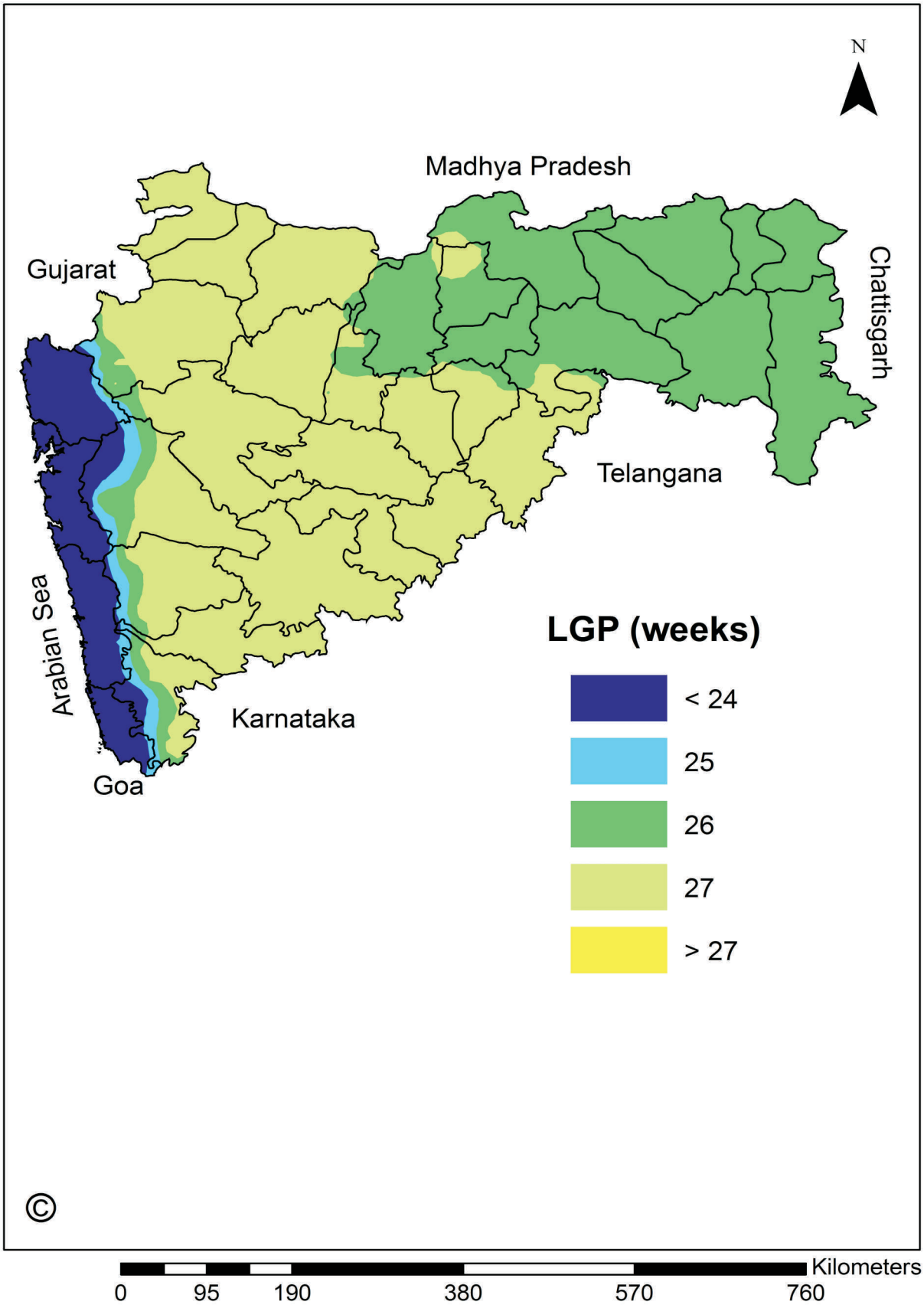

Fig. 86 c: Commencement of growing season (SMW) for soils having water holding capacity of 150 mm in Maharashtra

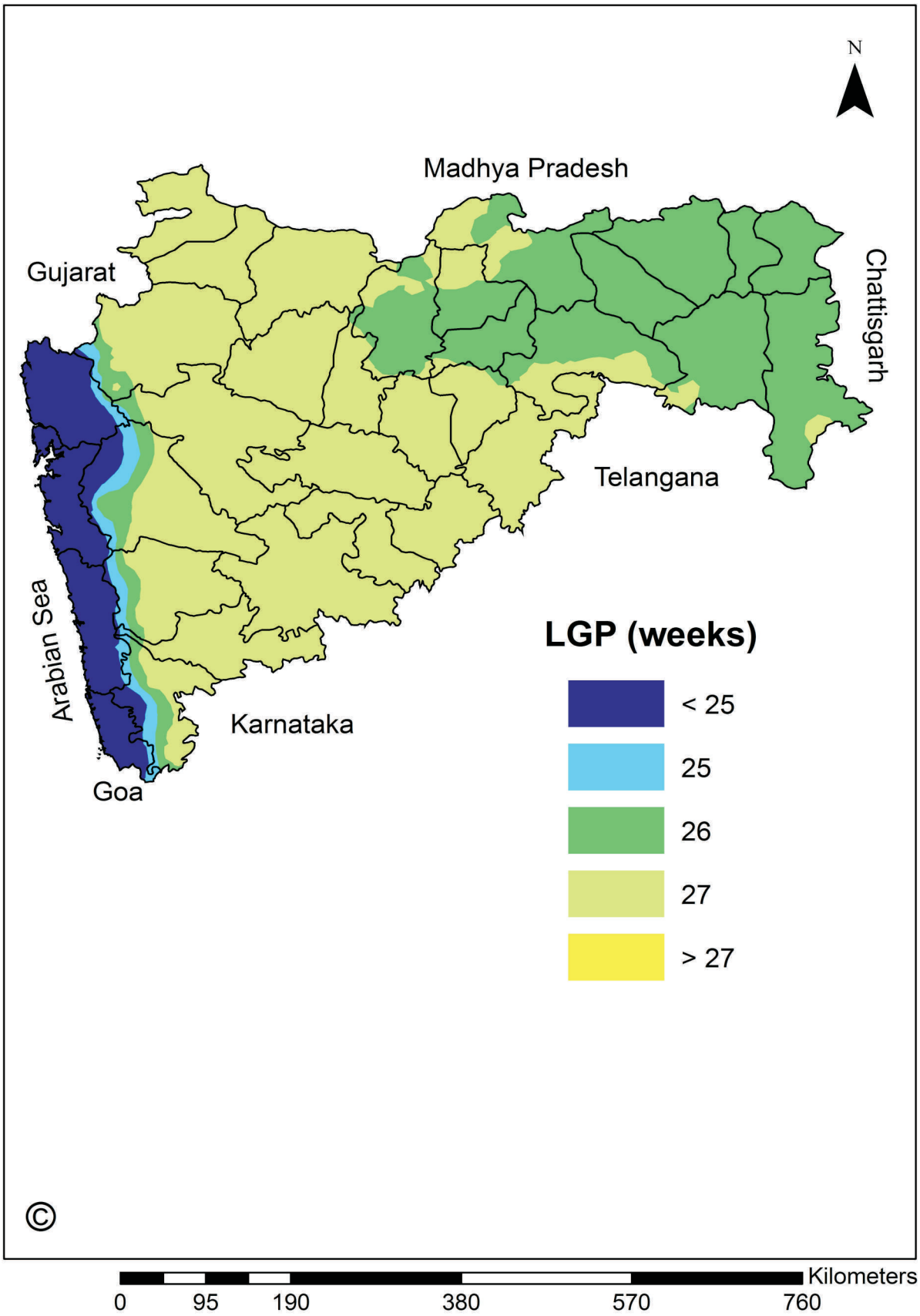

Fig. 86 d : Commencement of growing season (SMW) for soils having water holding capacity of 200 mm in Maharashtra

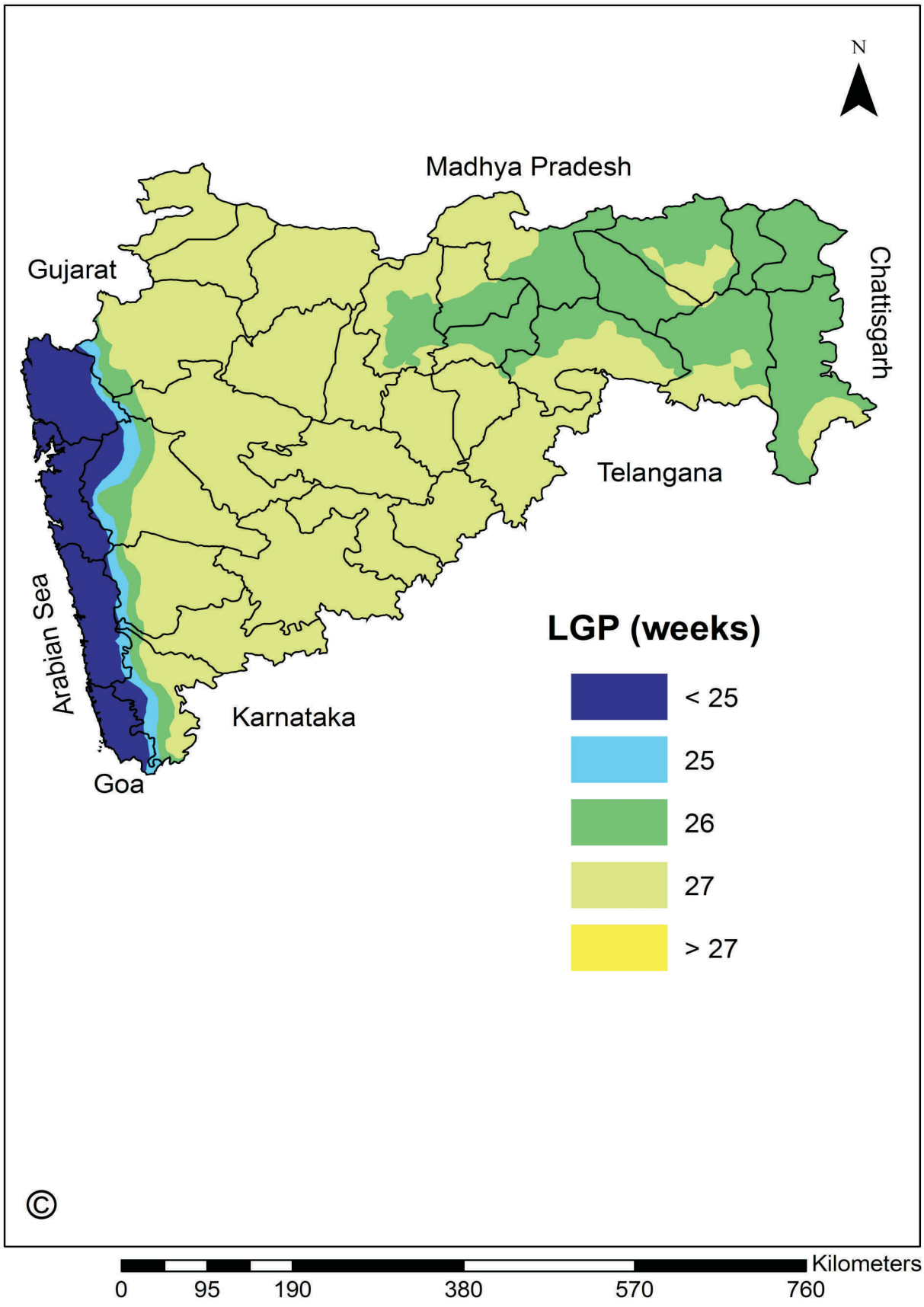

Fig. 86 e: Commencement of growing season (SMW) for soils having water holding capacity of 250 mm in Maharashtra

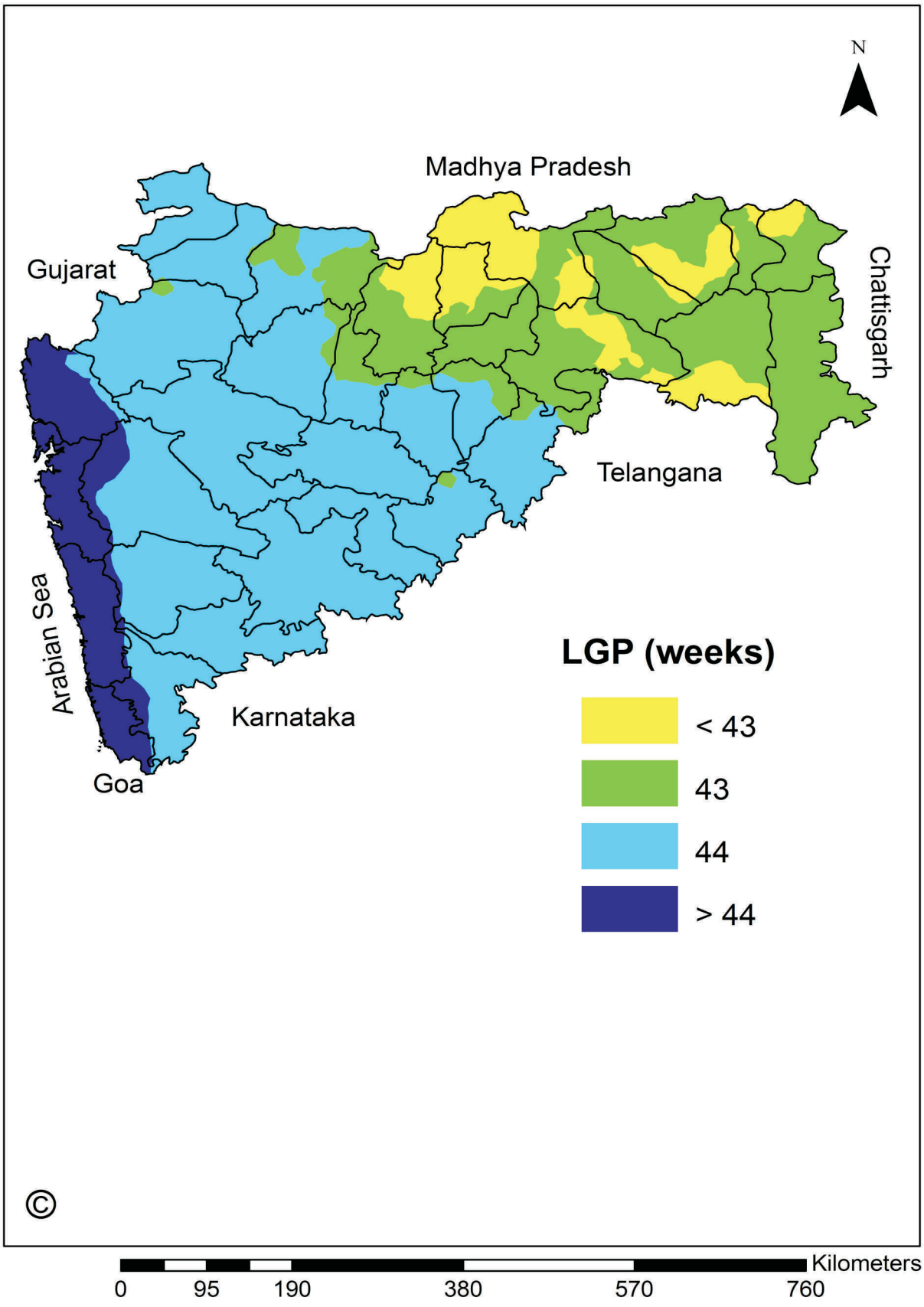

Fig. 87 a: Termination of growing season (SMW) for soils having water holding capacity of 50 mm in Maharashtra

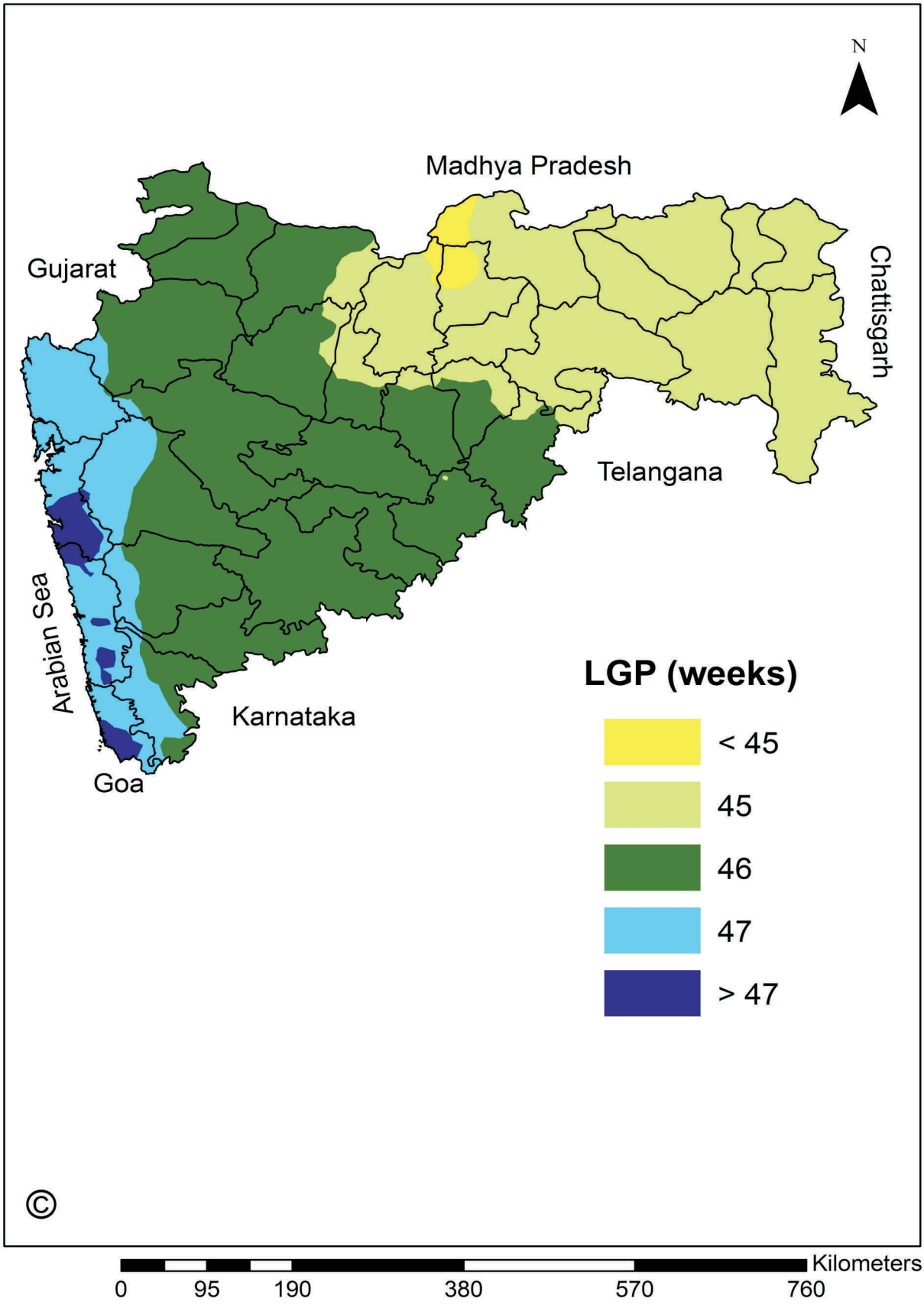

Fig. 87 b: Termination of growing season (SMW) for soils having water holding capacity of 100 mm in Maharashtra

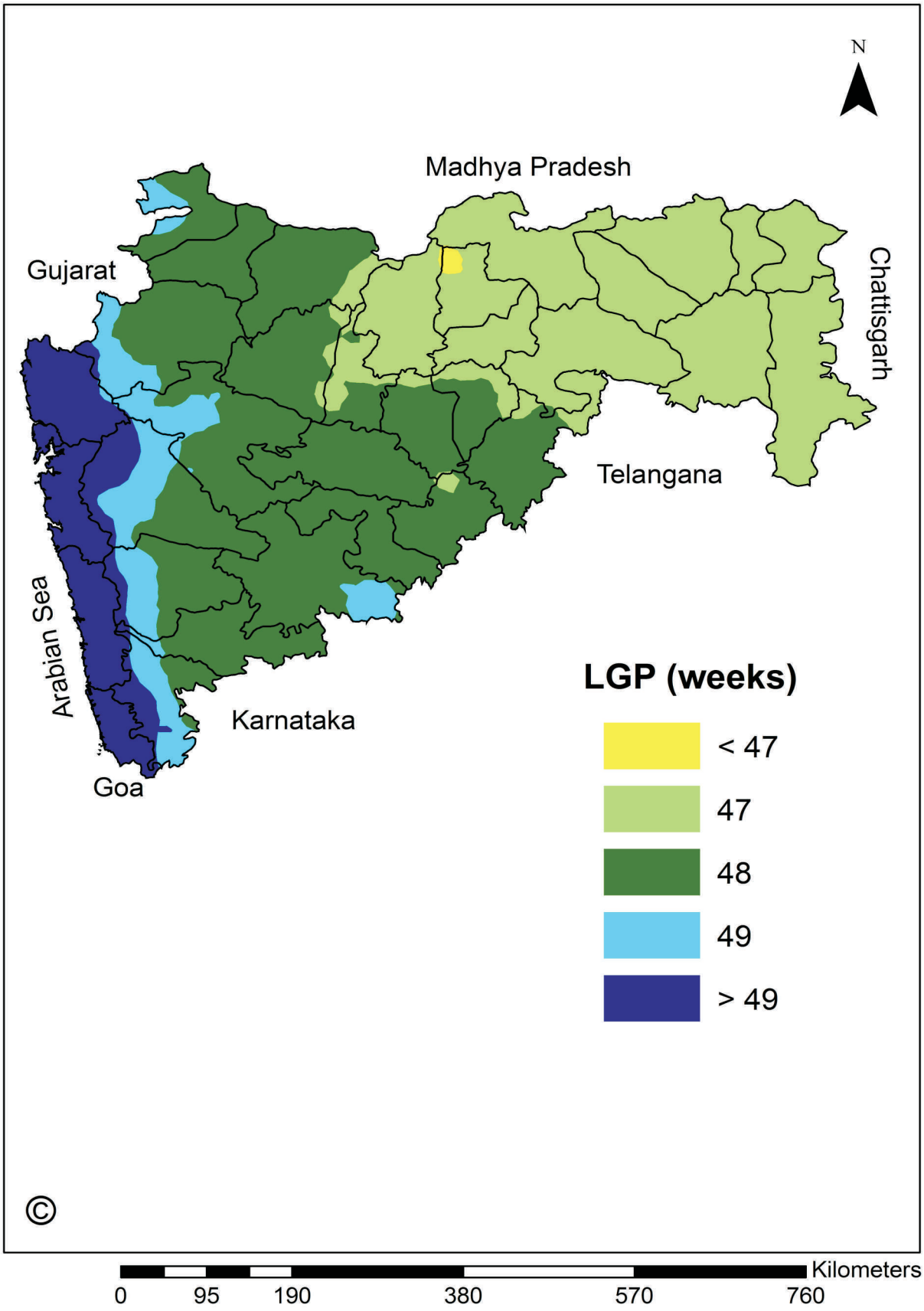

Fig. 87 c: Termination of growing season (SMW) for soils having water holding capacity of 150 mm in Maharashtra

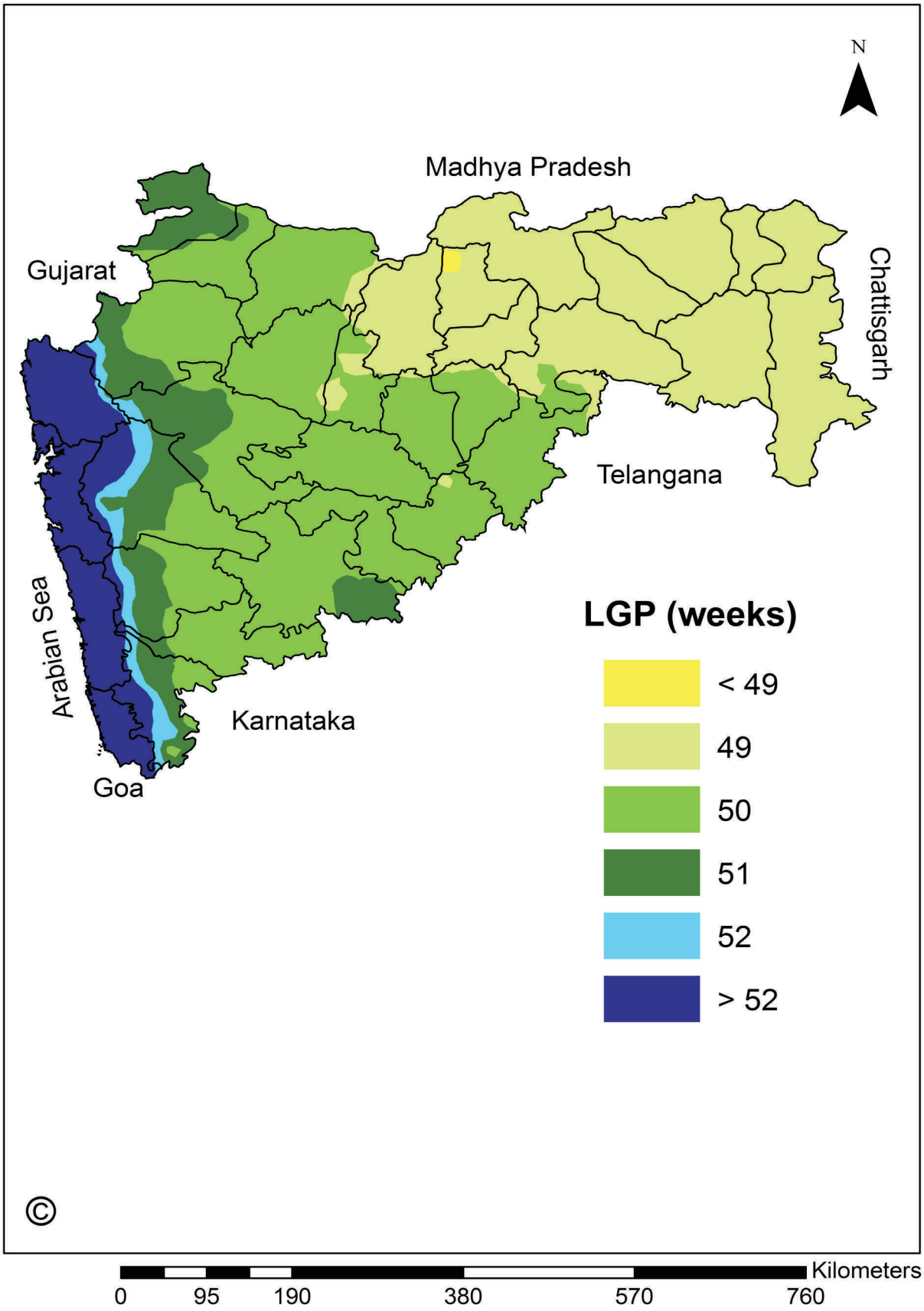

Fig. 87 d : Termination of growing season (SMW) for soils having water holding capacity of 200 mm in Maharashtra

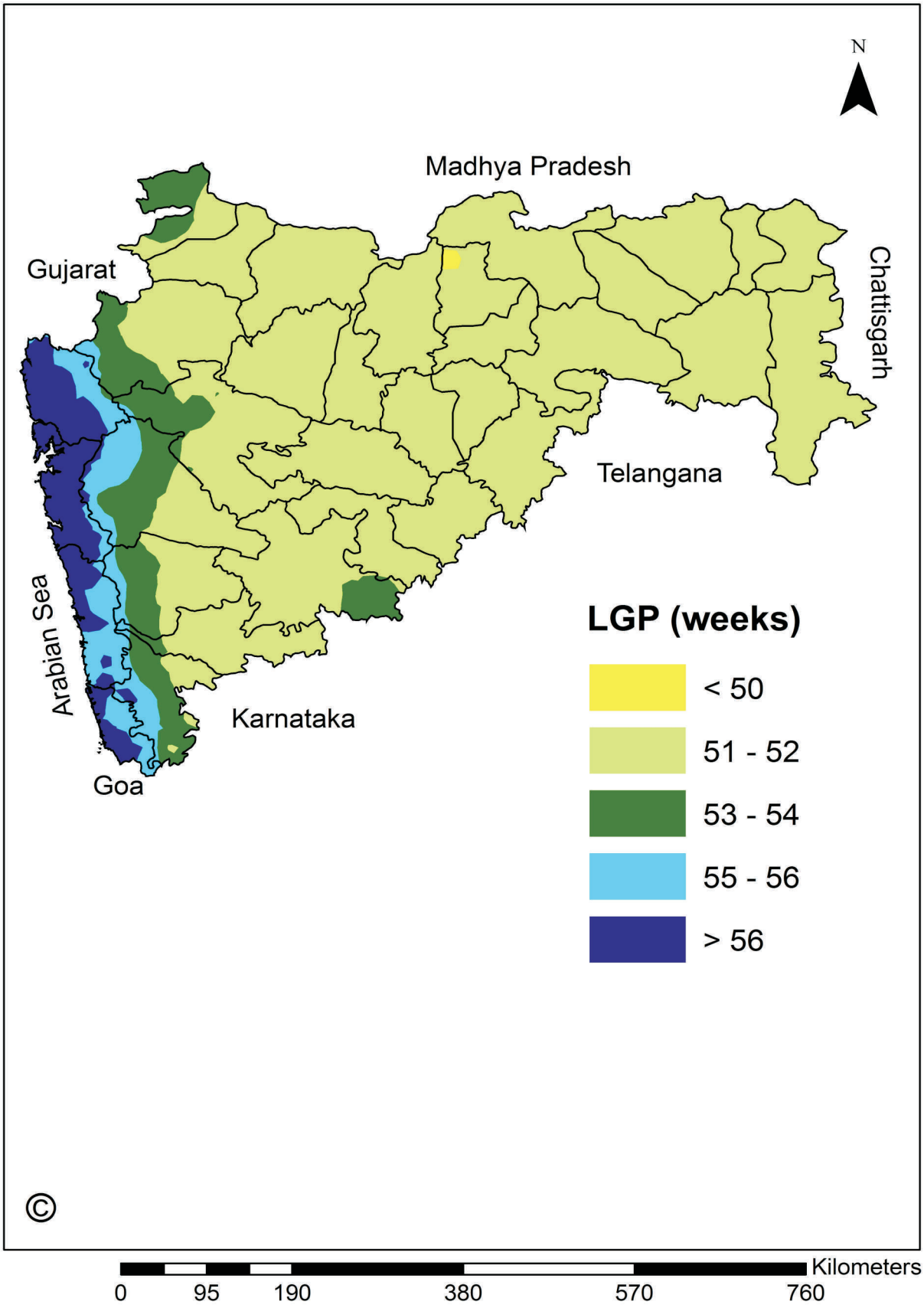

Fig. 87 e: Termination of growing season (SMW) for soils having water holding capacity of 250 mm in Maharashtra

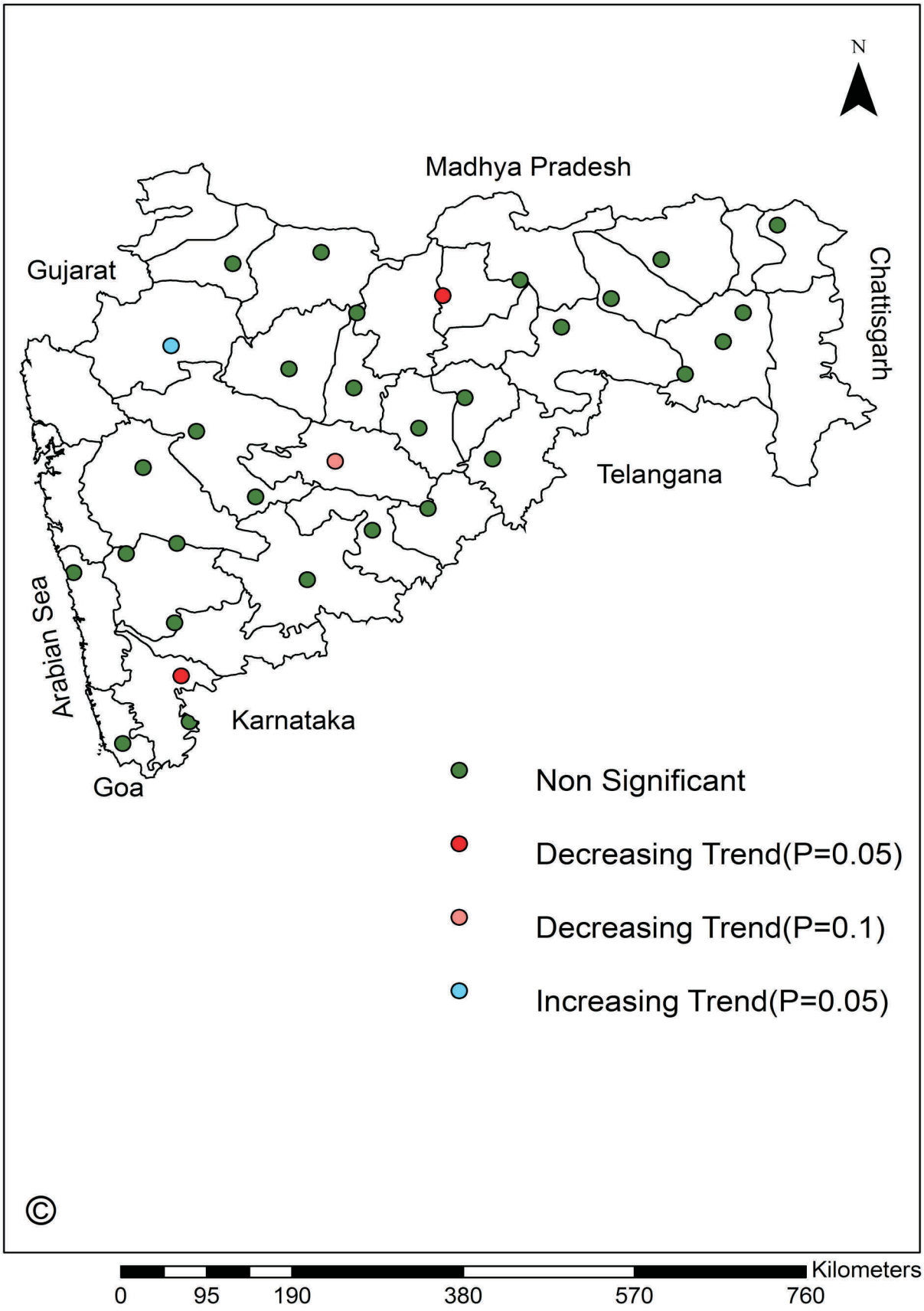

Fig. 88: Areas showing changes in maximum one-day rain episodes in Maharashtra

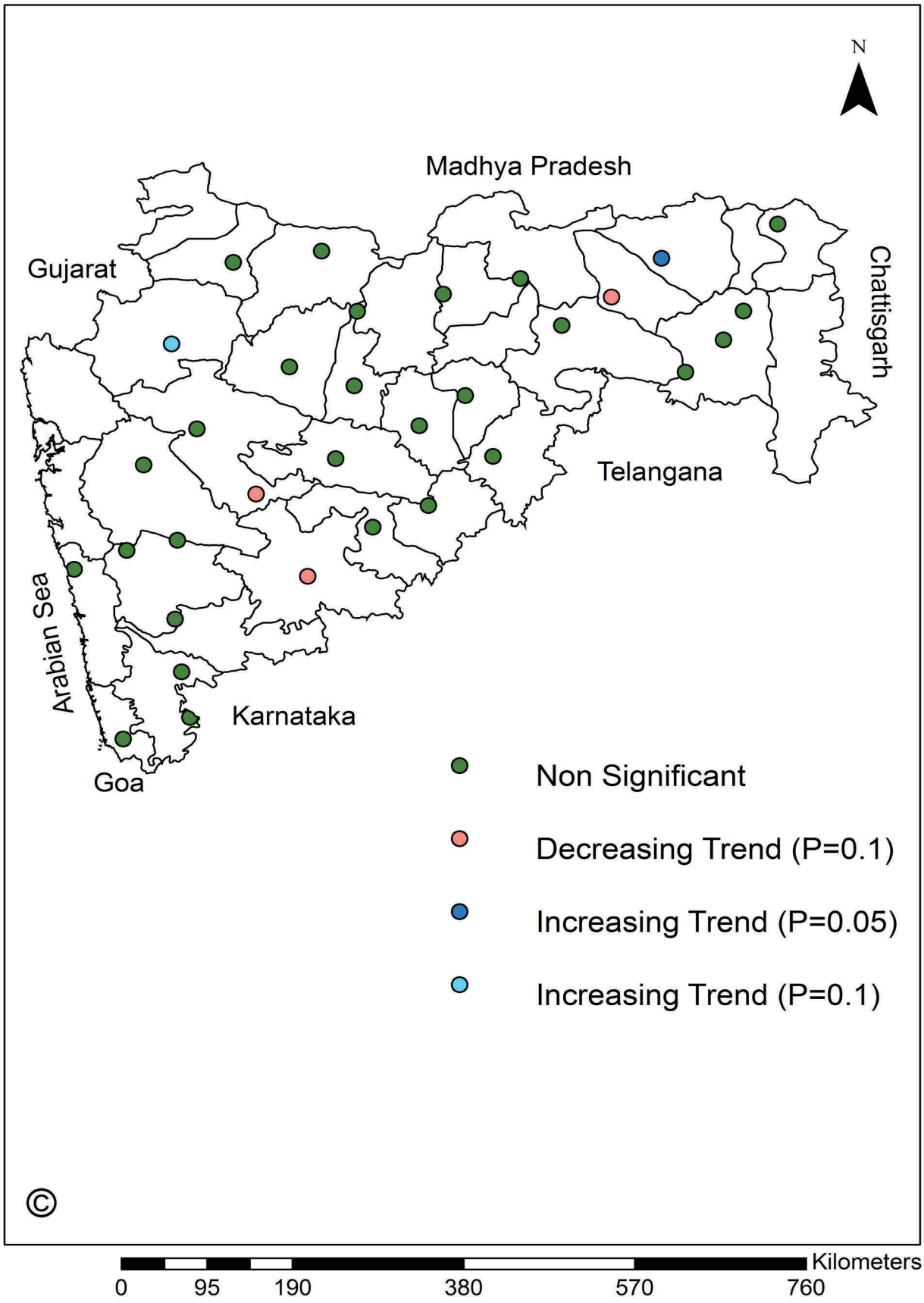

Fig. 89: Areas in Maharashtra showing changes in maximum five-day total

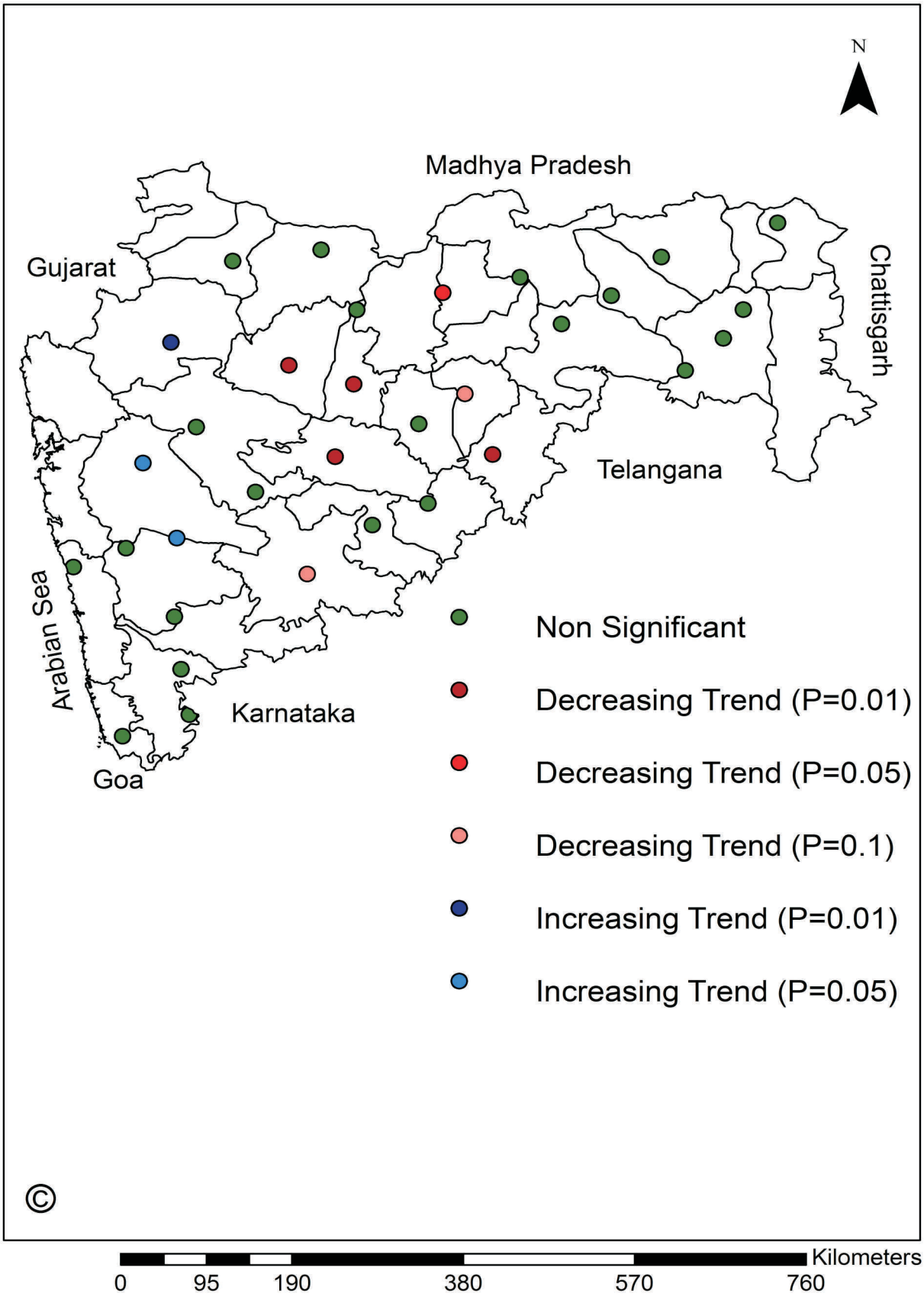

Fig. 90: Areas in Maharashtra showing changes in mean daily rainfall intensity

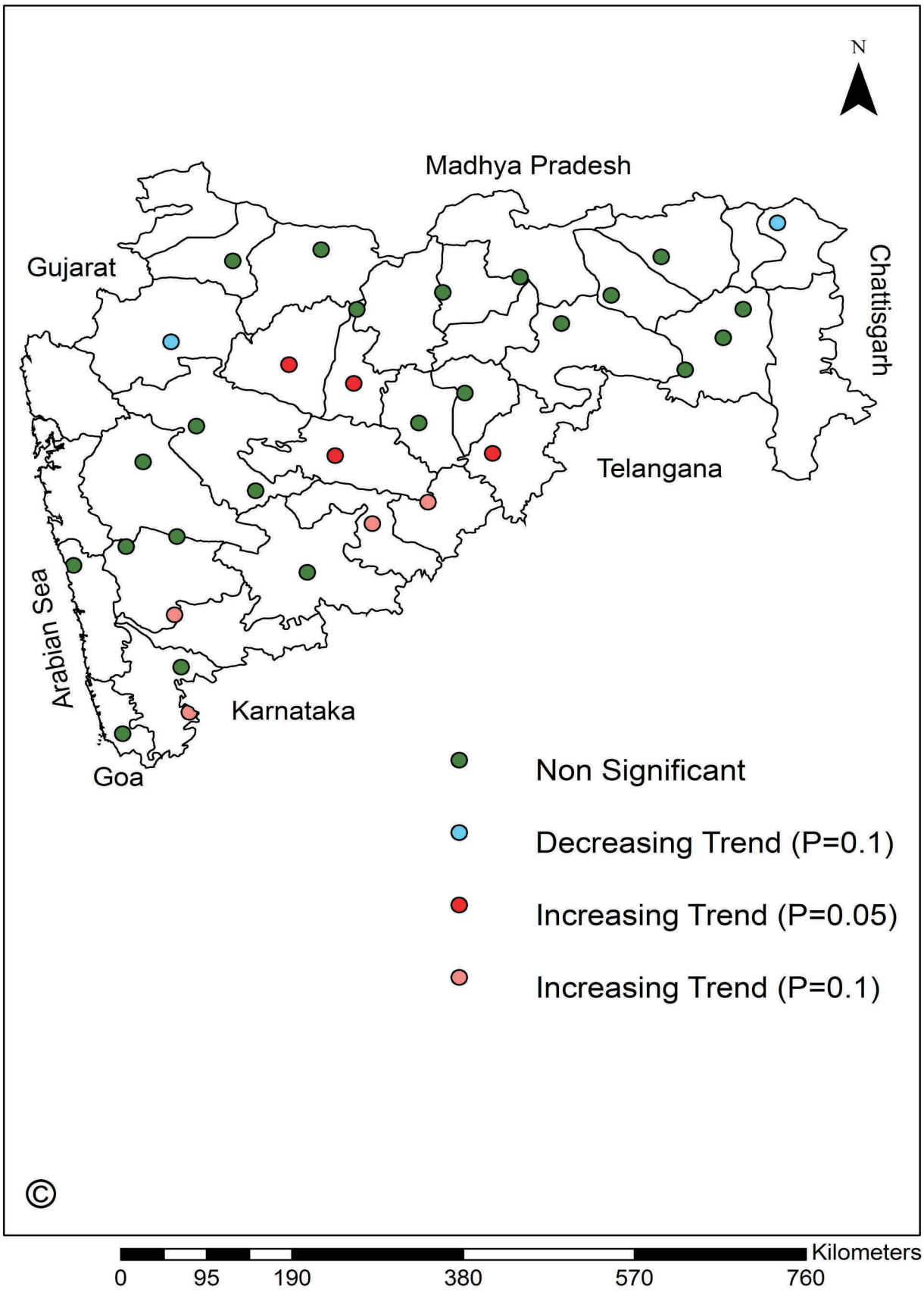

Fig. 91: Areas showing changes in maximum length of dry spell in Maharashtra

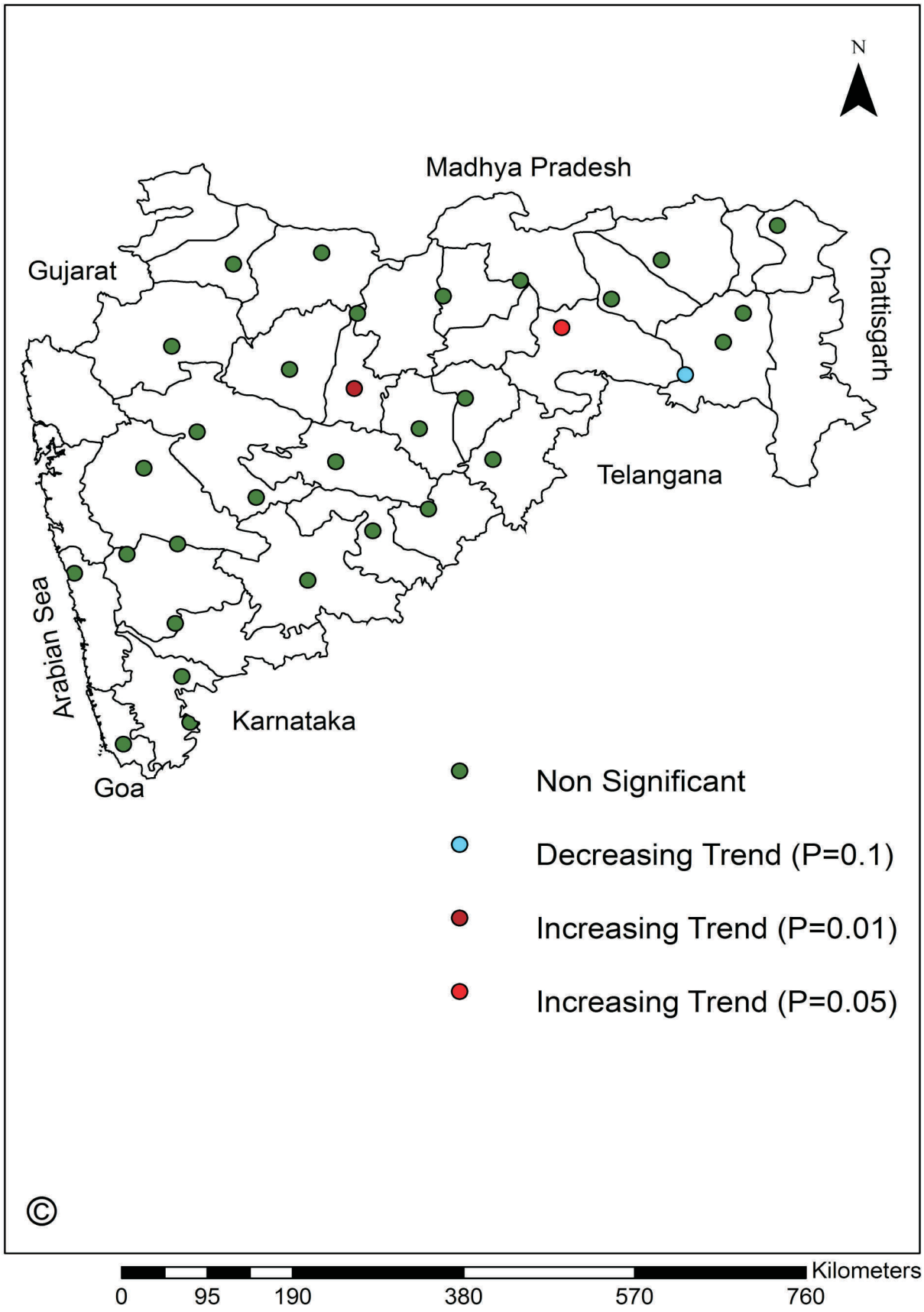

Fig. 92: Areas showing changes in maximum length of wet spells in Maharashtra

5. Temperature

5.1. Maximum Temperature

The mean annual temperature of the state is 32.8°C. A peak occurs during summer season (38.1°C) and the lowest temperature is recorded during winter season (30.9°C). Average temperatures are ± 31.3°C during SWM season and ±31.0°C during post monsoon season. Regionally the mean annual temperature is higher in Vidarbha (33.1°C), followed by *Konkan* (33.0°C), *Marathwada* (32.9°C) and *Madhya Maharashtra* (32.3°C). *Konkan* region experiences relatively low temperatures during SWM and summer seasons but higher temperatures during post monsoon and winter seasons compared to the three other regions of the state. The spatial distribution of annual temperature (Fig. 93) shows a range of 30.3 to 34.3°C across various locations in the state. Highest temperatures (>34.0°C) are recorded at Kudal in the southernmost district of Sindhudurg and northerly Jalgaon. The mean annual temperatures are in the range of 33.0 to 34.0°C in major parts of Vidarbha, Latur and Parbhani in *Marathwada*, Solpaur and Dhule in *Madhya Maharashtra* and Karjat in Konkan region. Mean maximum temperatures in the remaining districts range from 31.0 to 33.0 °C.

On a monthly basis, April and May months are the warmest in all the four regions of the state. Highest mean maximum temperature (39.6°C) is observed in the month of May. *Vidarbha* region is the warmest (42.0°C) followed by *Marathwada* (40.1°C). *Konkan* (35.6°C) and *Madhya Maharashtra* (35.5°C) district locations are somewhat cooler in the month of May (Table 18). Lowest monthly mean maximum temperature is observed in the month of December in Vidarbha (28.7°C) and *Marathwada* (29.6°C) regions and in the month of August in *Konkan* (28.6°C) and *Madhya Maharashtra* (29.0°C).

Jalgaon, Dhule, Chandrapur, Akola, Solapur, Gondia, Nagpur and Osmanabad experience relatively warm climate during SWM period (32.7 to 33.6°C). Whereas Igatpuri, Kolhapur, Pune, Dapoli, Niphad and Buldhana experiences comparatively cool weather (26.6 to 29.9°C) during the corresponding period (Fig. 94) Temperatures during post monsoon period are the lowest in Vidarbha region (30.5°C), followed by Marathwada (30.7°C), Madhya Maharashtra (30.8°C) and highest in Konkan (33.1°C) (Fig. 95). Locally the highest mean maximum temperatures during summer are at Chandrapur (40.6°C), followed by Jalgaon (40.4°C), Akola (40.2°C) and Wardha (40.1°C) (Fig. 96). Mean maximum temperatures during winter season are lowest in *Vidarbha* region (30.2°C), followed by *Madhya Maharashtra* (30.8°C), *Marathwada* (30.9°C), and highest in *Konkan* (33.1°C) (Fig. 97).

5.2. Minimum Temperature

The state as a whole experiences a minimum temperature of 19.2°C on an annual basis. However, there are regional differences. The spatial distribution of annual minimum temperature is depicted in Fig. 98 which shows a range of 16.8 to 21.7°C across the state. Regional average shows the highest annual mean minimum temperature in Vidarbha (19.8°C) and the lowest in Madhya Maharashtra (18.5°C). Latur in *Marathwada* records highest annual minimum temperature of 21.7°C while Padegaon in *Madhya Maharashtra* records the lowest (16.8°C).

On average monthly basis, minimum temperatures are lowest (13.2°C) in the months of December and January over the state. December is the coolest month in *Madhya Maharashtra, Vidarbha* and *Marathwada* whereas January is the coolest month in *Konkan* region. Minimum temperatures are high during the month of May over the entire state (25.1°C). *Vidarbha* region records highest temperature (27.1°C) in May month. *Madhya Maharashtra* (23.3°C) experiences relatively lower minimum temperatures compared to the other regions during May. Within the region also warmer locations (25.5 to 27.8°C) during May are majorly across *Vidarbha* region and relatively cooler locations (21.5 to 26.8°C) majorly in *Madhya Maharashtra*. During December, cooler temperatures prevail over *Madhya Maharashtra* (12.4°C) followed by *Vidarbha* (13.1°C) and *Marathwada* (13.7°C). *Konkan* region experiences relatively higher mean minimum temperatures (14.9°C) during December (Table. 19).

During the SWM season, *Konkan* region experiences high minimum temperatures of 23.7°C followed by *Vidarbha* (23.0°C) which are comparatively lower over *Madhya Maharashtra* (22.1°C) and Marathwada (21.6°C) regions (Fig. 99). Karjat, Jalgaon, Dhule, Chandrapur, Gondia and Nagpur experience relatively warm climate (24.0 to 24.8°C) during SWM period. This is could be due to presence of prolonged cloudy conditions. Nanded, Osmanabad, Kolhapur and Igatpuri experience cooler range of SWM season minimum temperatures (20.4 to 20.9°C).

Mean seasonal minimum temperatures for post monsoon period (Fig. 100) on a regional basis are higher over *Konkan* (18.3°C) and are least in *Madhya Maharashtra* (15.5°C). Kudal in *Konkan* is the warmest (20.3°C) during this season. Post monsoon season temperatures range between 14.6 to 18.8°C over *Marathwada*, 16.9 to 20.3°C over *Konkan*, 14.2 to 16.8°C in *Madhya Maharashtra* and 14.7 to 17.7 in *Vidarbha* region.

During summer season mean minimum temperatures are higher over *Vidarbha* (23.9°C) and lower over *Madhya Maharashtra* region (Fig.101). Latur in *Marathwada* (25.6°C) and Chandrapur in *Vidarbha* (25.0°C) are the warmest locations during this season. Whereas Niphad (17.4°C), Igatpuri (18.3°C) and Rahuri (18.6°C) in *Madhya Maharashtra* are the cooler. *Marathwada* (15.1°C) is the warmest region during the winter season followed by *Vidarbha* (14.8°C), *Konkan* (14.4°C) and *Madhya Maharashtra* (12.7°C) (Fig.102). Latur (19.3°C) in *Marathwada* is the warmest and Padegaon in *Madhya Maharashtra* records cooler mean minimum temperature (11.3°C) during the winter season.

Table. 24 : District wise average mean monthly and seasonal maximum temperature (°C) in Maharashtra

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	PM
Dapoli	31.0	31.4	32.5	32.7	32.9	30.2	28.1	27.8	28.8	31.6	32.6	31.7	30.9	31.2	32.7	28.7	31.9
Karjat	33.0	34.9	38.1	39.2	38.4	33.2	29.5	28.9	30.6	33.7	34.4	33.6	33.9	33.9	38.6	30.5	33.9
Kudal	33.8	34.7	35.4	35.9	35.4	31.3	29.1	29.2	30.3	33.0	34.1	33.8	34.3	34.2	35.6	30	33.6
Average Konkan	**32.6**	**33.7**	**35.3**	**35.9**	**35.6**	**31.6**	**28.9**	**28.6**	**29.9**	**32.8**	**33.7**	**33.0**	**33.0**	**33.1**	**35.6**	**29.7**	**33.1**
Dhule	29.8	32.6	37.0	40.6	41.7	37.5	32.8	31.2	32.5	34.3	32.2	30.1	33.0	31.1	39.8	33.4	32.2
Jalgaon	30.1	32.9	37.5	41.3	42.4	37.9	32.7	30.9	32.8	34.7	32.7	30.4	34.6	31.4	40.4	33.6	32.6
Kolhapur	30.2	32.7	35.6	37.0	35.7	30.2	27.2	27.1	29.0	30.7	30.3	29.6	31.2	31.4	36.1	28.3	30.2
Igatpuri	29.2	31.3	34.6	37.0	35.4	29.0	25.0	25.2	27.5	30.4	30.3	29.6	30.3	30.2	35.6	26.6	30.1
Niphad	28.4	30.5	34.5	37.5	37.7	33.2	29.1	27.9	29.6	32.1	30.3	28.5	31.6	29.4	36.6	29.9	30.3
Padegaon	29.4	32.0	35.5	37.9	37.2	32.2	29.5	28.9	30.4	31.4	29.9	28.6	31.9	30.6	36.9	30.2	30
Pune	29.8	32.0	35.5	37.7	37.1	31.9	28.5	27.8	29.5	31.5	30.4	29.2	31.7	30.9	36.7	29.4	30.4
Rahuri	28.9	31.2	34.9	37.9	38.7	34.1	30.8	30.1	30.8	31.6	30.1	28.7	32.3	30	37.1	31.4	30.1
Solapur	30.9	33.9	37.5	39.9	40.2	35.3	32.6	31.6	32.2	32.6	31.4	30.4	34.0	32.4	39.2	32.9	31.5
Average Madhya Maharashtra	**29.6**	**32.1**	**35.8**	**38.5**	**38.5**	**33.5**	**29.8**	**29.0**	**30.5**	**32.1**	**30.8**	**29.5**	**32.3**	**30.8**	**37.6**	**30.6**	**30.8**
Aurangabad	29.0	32.0	35.3	38.8	39.7	34.4	29.7	29.1	30.2	31.8	30.3	29.1	32.4	30.4	37.9	30.9	30.4
Jalana	30.4	32.6	35.9	38.5	40.4	34.3	30.4	29.6	30.6	31.6	30.4	29.3	32.8	31.4	38.3	31.2	30.4
Latur	30.7	33.2	36.7	38.8	39.7	34.6	31.4	30.1	31.2	31.7	30.5	29.6	33.2	31.9	38.4	31.8	30.6
Nanded	28.7	31.0	34.2	37.8	39.7	35.3	31.1	30.7	30.9	31.9	31.0	30.1	32.7	29.8	37.3	32	31
Osmanabad	29.4	31.5	34.8	37.4	39.5	36.3	30.6	29.3	29.8	30.9	30.6	29.9	32.5	30.4	37.3	31.4	30.5
Parbhani	30.0	32.8	36.7	40.1	41.3	36.3	32.0	30.7	31.8	32.7	31.0	29.5	33.7	31.4	39.3	32.7	31.1
Average Marathwada	**29.7**	**32.2**	**35.6**	**38.6**	**40.1**	**35.2**	**30.9**	**29.9**	**30.8**	**31.8**	**30.6**	**29.6**	**32.9**	**30.9**	**38.1**	**31.7**	**30.7**
Akola	29.7	32.6	37.1	41.0	42.4	37.3	32.1	30.4	32.1	33.6	31.6	29.6	34.0	31.1	40.2	32.9	31.6
Amravati	29.3	32.0	36.5	40.5	41.9	36.6	31.2	29.6	31.6	33.1	31.0	29.2	33.4	30.6	39.6	32.2	31.1
Buldhana	27.7	30.3	34.3	37.9	38.7	33.8	29.1	27.7	29.2	30.6	29.1	27.6	31.2	28.9	37.0	29.9	29.1
Chandrapur	30.2	33.2	37.5	41.3	42.9	37.4	31.9	30.6	32.3	32.7	30.9	29.6	34.1	31.6	40.6	33.0	31.1
Bramhapuri	29.1	32.0	36.5	40.6	42.6	37.4	31.2	30.3	31.7	32.6	30.7	29.0	33.5	30.5	39.9	32.6	30.8
Sindewahi	28.8	32.1	36.4	40.0	42.5	36.5	30.5	30.2	31.3	31.5	30.1	28.4	33.0	30.4	39.6	32.1	30.0
Gondia	28.0	30.8	35.9	40.2	42.2	37.1	31.1	30.3	31.8	32.5	30.5	28.5	32.9	29.3	39.4	32.5	30.5
Nagpur	28.3	31.1	35.9	40.4	42.6	37.6	31.5	30.3	31.9	32.6	30.4	28.3	33.1	29.6	39.6	32.8	30.4
Wardha	28.8	31.8	36.7	41.0	42.7	37.2	31.7	30.2	31.8	32.6	30.3	28.7	33.4	30.2	40.1	32.7	30.6
Yavatmal	28.6	31.6	35.8	40.0	41.5	36.3	30.5	29.1	30.9	31.7	30.0	28.4	32.7	30.0	39.1	31.7	30.0
Average Vidarbha	**28.9**	**31.8**	**36.3**	**40.3**	**42.0**	**36.7**	**31.1**	**29.9**	**31.5**	**32.4**	**30.5**	**28.7**	**33.1**	**30.2**	**39.5**	**32.2**	**30.5**
Average State	**29.8**	**32.2**	**35.9**	**38.8**	**39.6**	**34.7**	**30.3**	**29.4**	**30.8**	**32.2**	**31.0**	**29.7**	**32.8**	**30.9**	**38.1**	**31.3**	**31.0**

Table. 25 : District wise average mean monthly and seasonal minimum temperature (°C) in Maharashtra

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	PM
Dapoli	12.2	12.6	15.8	19.7	22.9	23.8	23.3	23.0	22.3	20.5	16.9	13.3	18.8	12.4	19.5	23.1	16.9
Karjat	13.5	14.2	18.0	22.1	24.8	25.1	24.1	23.9	23.1	21.4	17.4	14.2	20.1	13.8	21.6	24.1	17.7
Kudal	16.7	17.2	20.6	23.7	25.2	24.5	23.9	23.8	23.6	23.3	20.5	17.2	19.7	16.9	23.1	23.9	20.3
Average Konkan	**14.1**	**14.7**	**18.1**	**21.8**	**24.3**	**24.5**	**23.8**	**23.6**	**23.0**	**21.7**	**18.3**	**14.9**	**19.5**	**14.4**	**21.4**	**23.7**	**18.3**
Dhule	12.0	13.9	18.4	23.1	26.1	25.6	24.2	23.4	22.7	19.8	15.7	12.3	21.6	12.9	22.5	24	15.9
Jalgaon	12.0	13.8	18.5	23.9	26.8	25.9	24.2	23.3	22.9	19.4	15.3	12.4	19.8	12.9	23.1	24.1	15.7
Kolhapur	13.7	15.0	18.0	20.8	22.0	21.7	21.1	20.6	20.1	19.6	16.8	14.0	18.6	14.3	20.3	20.9	16.8
Igatpuri	11.3	12.3	14.9	18.6	21.5	21.6	20.8	20.5	20.3	18.0	15.4	12.3	17	11.8	18.3	20.8	15.2
Niphad	11.8	11.9	13.0	17.7	21.5	22.6	21.9	21.1	20.2	17.1	13.4	12.0	17.2	11.9	17.4	21.4	14.2
Padegaon	10.7	12.0	15.9	20.2	22.5	22.6	21.9	21.3	20.8	18.9	14.4	11.0	16.8	11.3	19.5	21.6	14.8
Pune	11.0	12.3	15.7	19.8	22.6	22.9	22.3	21.5	20.8	18.6	14.6	11.4	17.7	11.6	19.4	21.9	14.9
Rahuri	11.8	12.2	15.0	19.0	21.7	22.7	22.2	21.6	20.7	18.3	14.5	12.0	17.6	12	18.6	21.8	14.9
Solapur	14.4	16.6	20.2	23.7	24.9	23.5	22.6	21.9	21.6	19.9	16.6	13.9	19.9	15.4	22.9	22.4	16.8
Average Madhya Maharashtra	**12.1**	**13.3**	**16.6**	**20.8**	**23.3**	**23.2**	**22.4**	**21.7**	**21.1**	**18.8**	**15.2**	**12.4**	**18.5**	**12.7**	**20.2**	**22.1**	**15.5**
Aurangabad	12.3	14.9	18.7	22.9	24.9	23.0	21.7	21.2	21.4	19.7	15.5	13.0	19.1	13.5	22.2	21.8	16.1
Jalana	15.3	17.4	21.0	23.3	25.0	23.4	21.7	21.4	21.3	19.6	17.0	14.6	20.0	16.3	23.1	22	17.1
Latur	18.3	20.5	23.9	26.1	27.0	24.2	21.8	21.1	21.2	20.8	18.6	16.9	21.7	19.3	25.6	22.1	18.8
Nanded	12.6	15.1	18.5	21.4	23.4	22.4	20.6	20.1	20.4	18.5	16.0	13.2	18.5	13.8	21.1	20.9	15.9
Osmanabad	13.8	16.0	19.7	22.4	23.5	21.6	20.3	19.9	19.9	18.5	15.5	13.4	18.7	14.9	21.9	20.4	15.8
Parbhani	11.8	13.9	17.6	21.8	25.1	24.0	22.7	22.1	21.8	18.6	14.3	10.9	18.8	12.8	21.5	22.6	14.6
Average Marathwada	**14.0**	**16.3**	**19.9**	**23.0**	**24.8**	**23.1**	**21.5**	**21.0**	**21.0**	**19.3**	**16.2**	**13.7**	**19.5**	**15.1**	**22.6**	**21.6**	**16.4**
Akola	11.6	13.9	18.3	23.5	27.3	25.7	23.7	23.0	22.4	18.8	14.3	11.1	18.5	12.7	23.0	23.7	14.7
Amravati	15.0	17.1	20.8	24.4	26.6	24.8	23.0	22.4	22.3	20.6	17.5	14.9	20.2	16.0	23.9	23.1	17.7
Buldhana	14.7	16.7	20.9	24.5	25.5	23.5	22.0	21.3	21.3	20.2	17.0	14.2	19.6	15.7	23.6	22.0	17.1
Chandrapur	14.6	17.3	21.3	25.5	28.3	26.6	24.5	24.1	23.9	21.6	16.6	13.3	20.7	15.9	25.0	24.8	17.2
Bramhapuri	13.1	16.0	20.1	24.8	27.8	26.3	23.9	23.6	23.6	21.1	16.5	12.7	20.0	14.5	24.2	24.3	16.8
Sindewahi	11.6	14.5	18.9	23.7	26.5	25.3	23.1	22.7	22.5	19.9	14.7	10.7	18.6	13.0	23.0	23.4	15.1
Gondia	13.2	15.9	20.0	24.6	27.8	26.6	24.2	24.0	23.7	21.4	16.6	12.8	20.1	14.5	24.1	24.6	17.0
Nagpur	12.0	14.6	18.3	23.1	27.4	26.3	24.2	23.7	23.4	20.2	15.3	11.5	19.1	13.2	22.9	24.4	15.7
Wardha	13.7	16.2	20.1	24.5	27.3	25.3	23.3	22.7	22.5	20.2	16.6	13.7	19.8	14.9	24.0	23.4	16.8
Yavatmal	14.8	17.1	20.8	24.7	27.0	24.6	22.5	21.8	21.9	20.0	16.9	14.5	20.0	15.9	24.1	22.7	17.2
Average Vidarbha	**13.6**	**16.2**	**20.1**	**24.4**	**27.1**	**25.5**	**23.4**	**22.9**	**22.8**	**20.6**	**16.4**	**13.1**	**19.8**	**14.8**	**23.9**	**23.6**	**16.7**
Average State	**13.2**	**15.0**	**18.7**	**22.6**	**25.1**	**24.1**	**22.7**	**22.2**	**21.9**	**19.8**	**16.1**	**13.2**	**19.2**	**14.1**	**22.1**	**22.7**	**16.4**

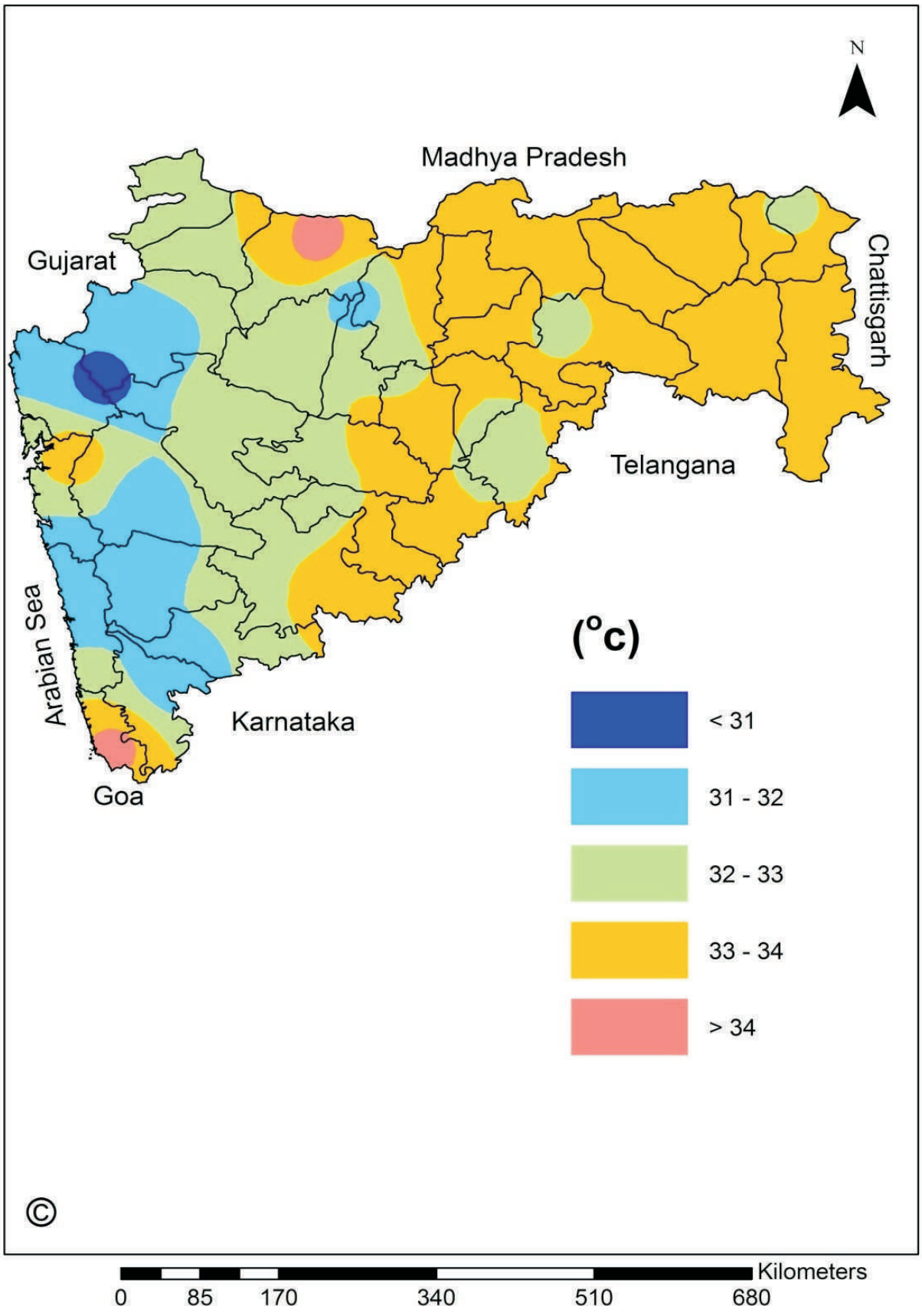

Fig. 93: Spatial distribution of annual mean maximum temperature in Maharashtra

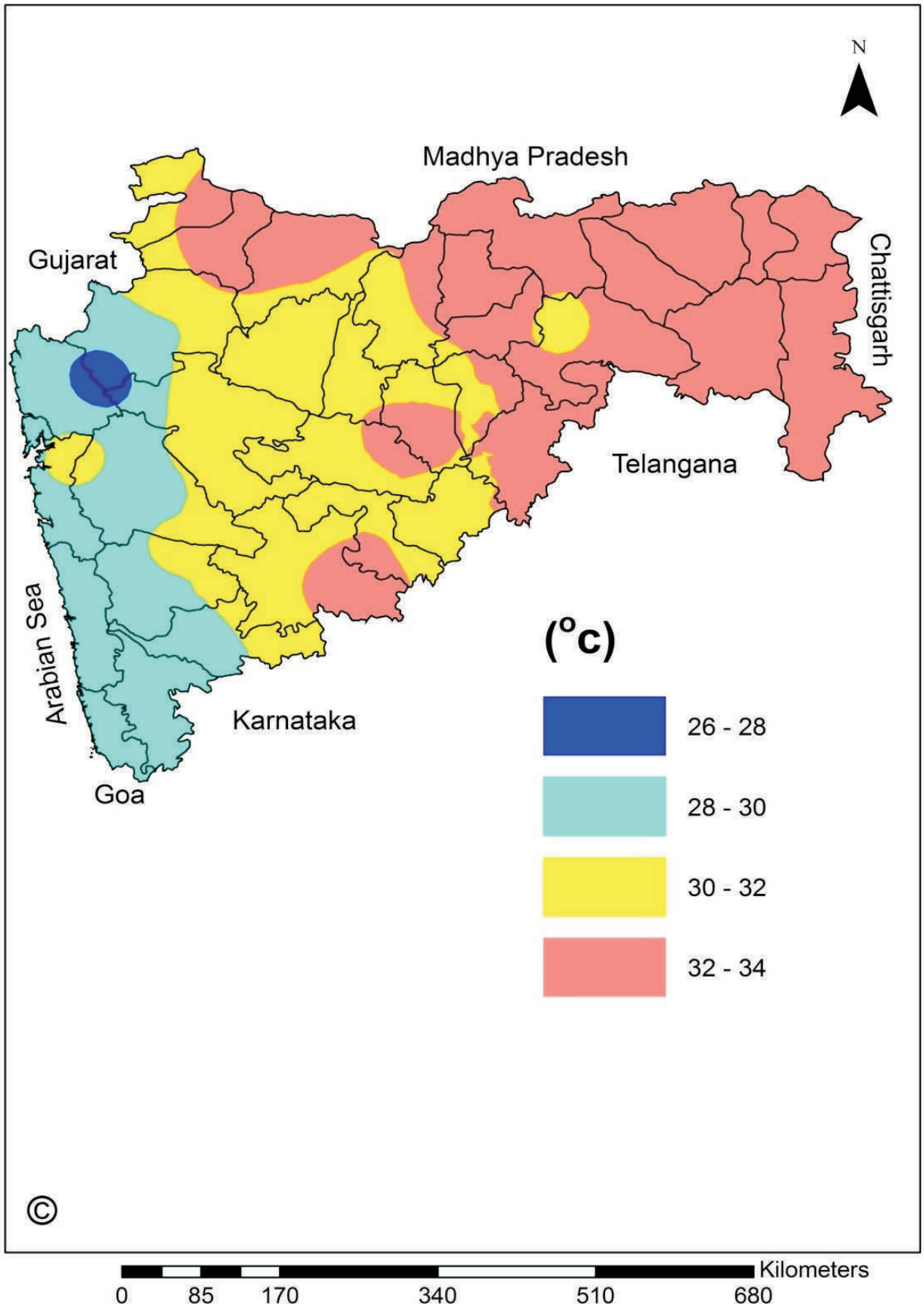

Fig. 94: Spatial distribution of mean Southwest monsoon season maximum temperature in Maharashtra

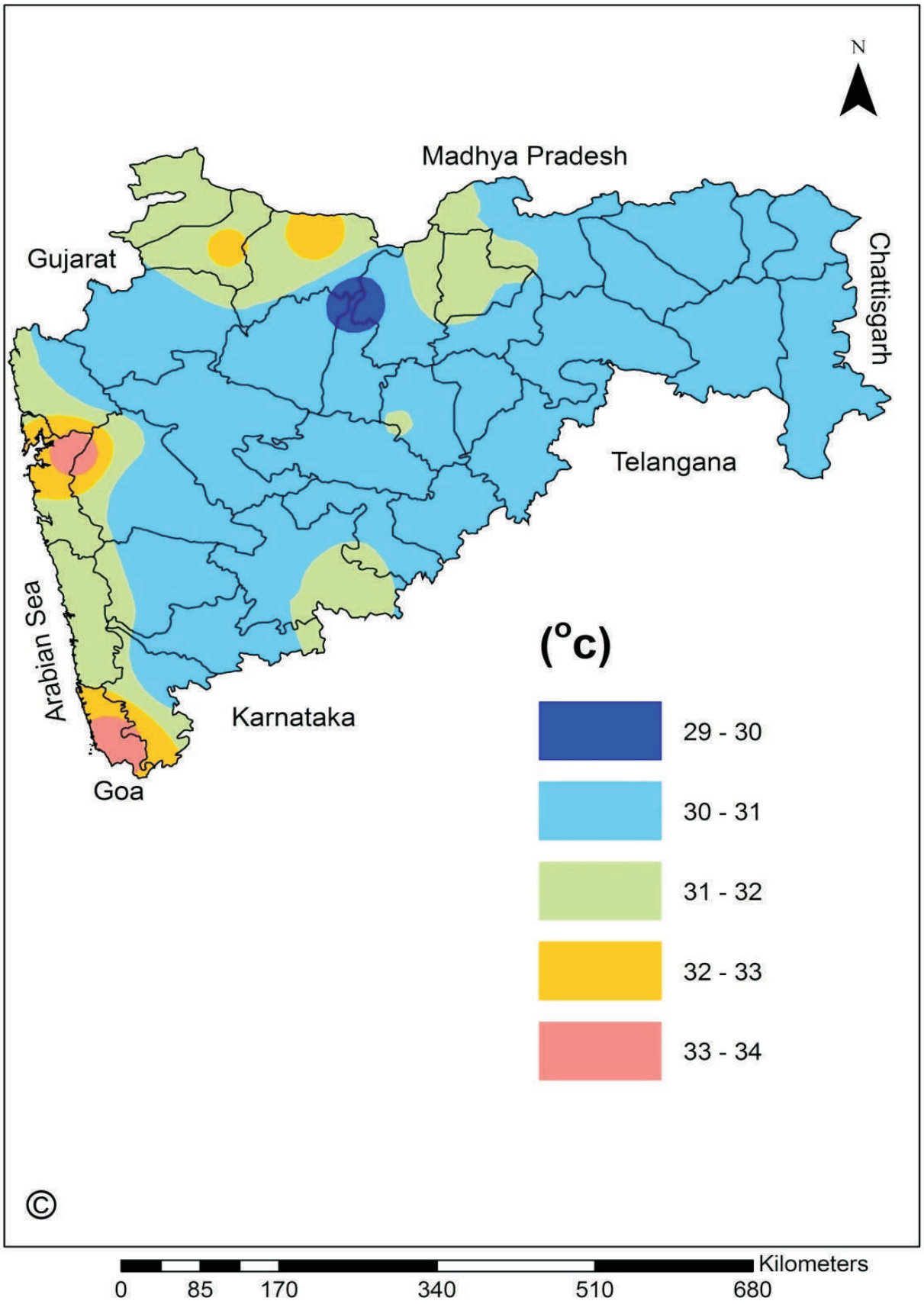

Fig. 95: Spatial distribution of mean post monsoon season maximum temperature in Maharashtra

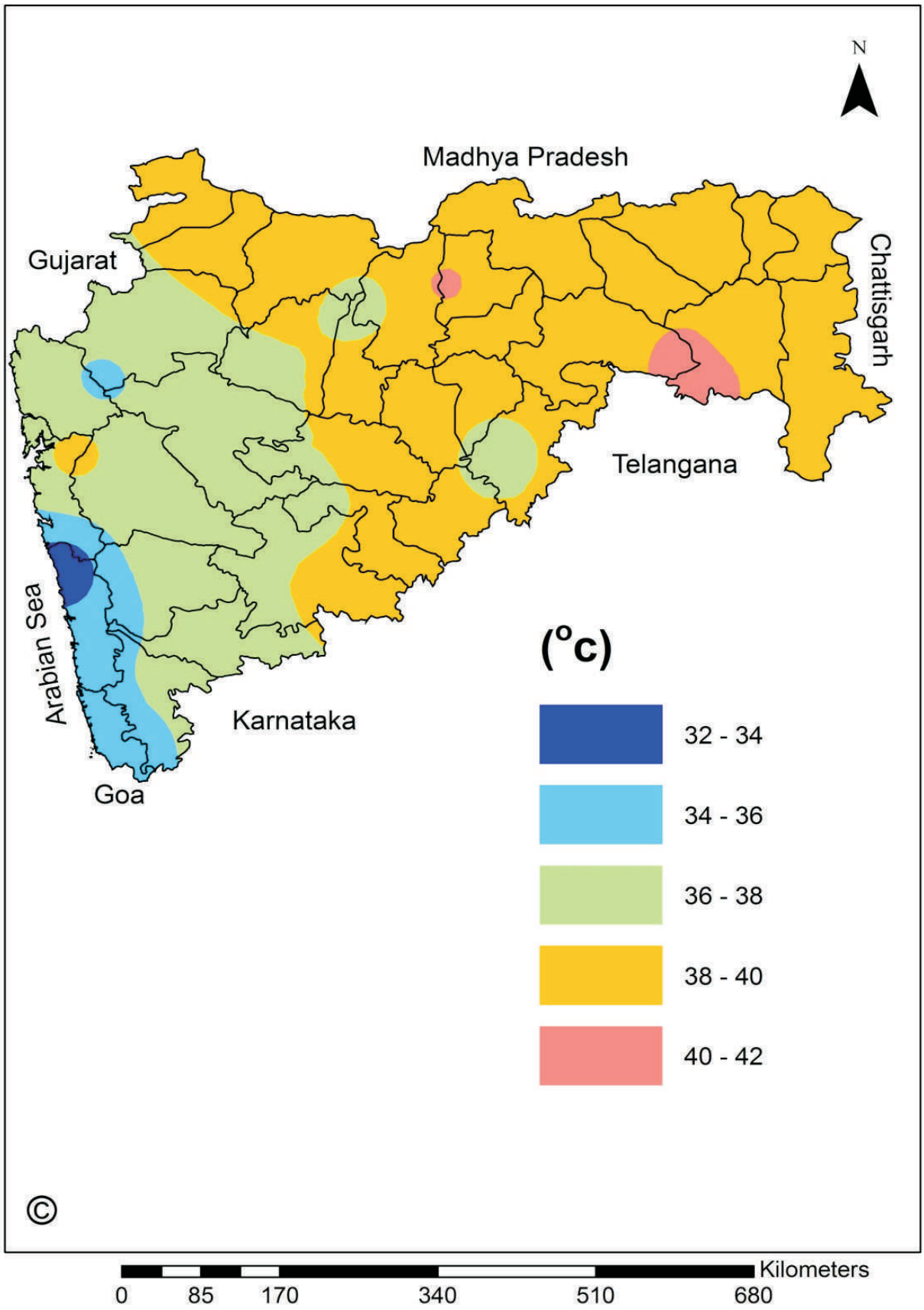

Fig. 96: Spatial distribution of mean summer season maximum temperature in Maharashtra

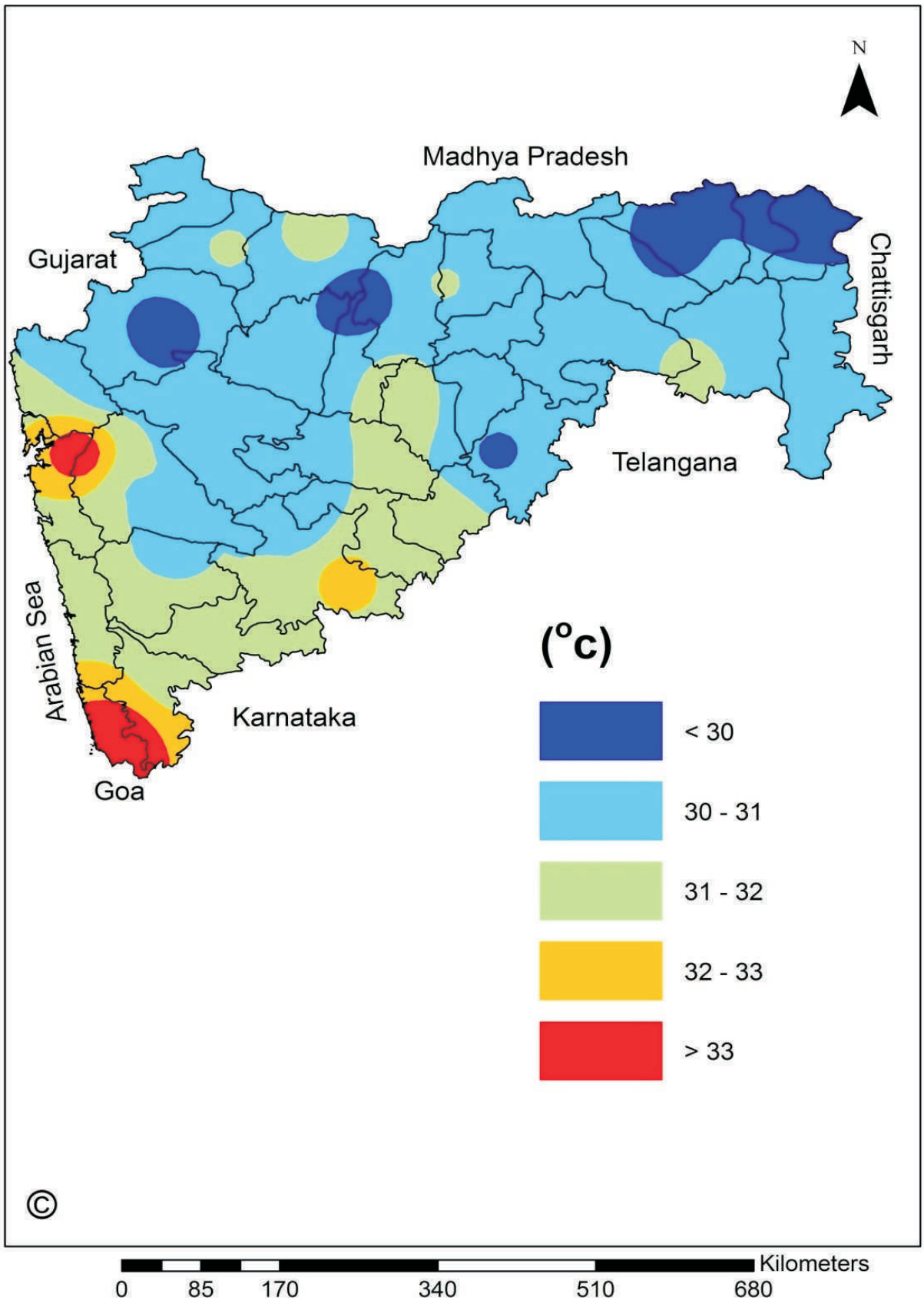

Fig. 97: Spatial distribution of mean winter season maximum temperature in Maharashtra

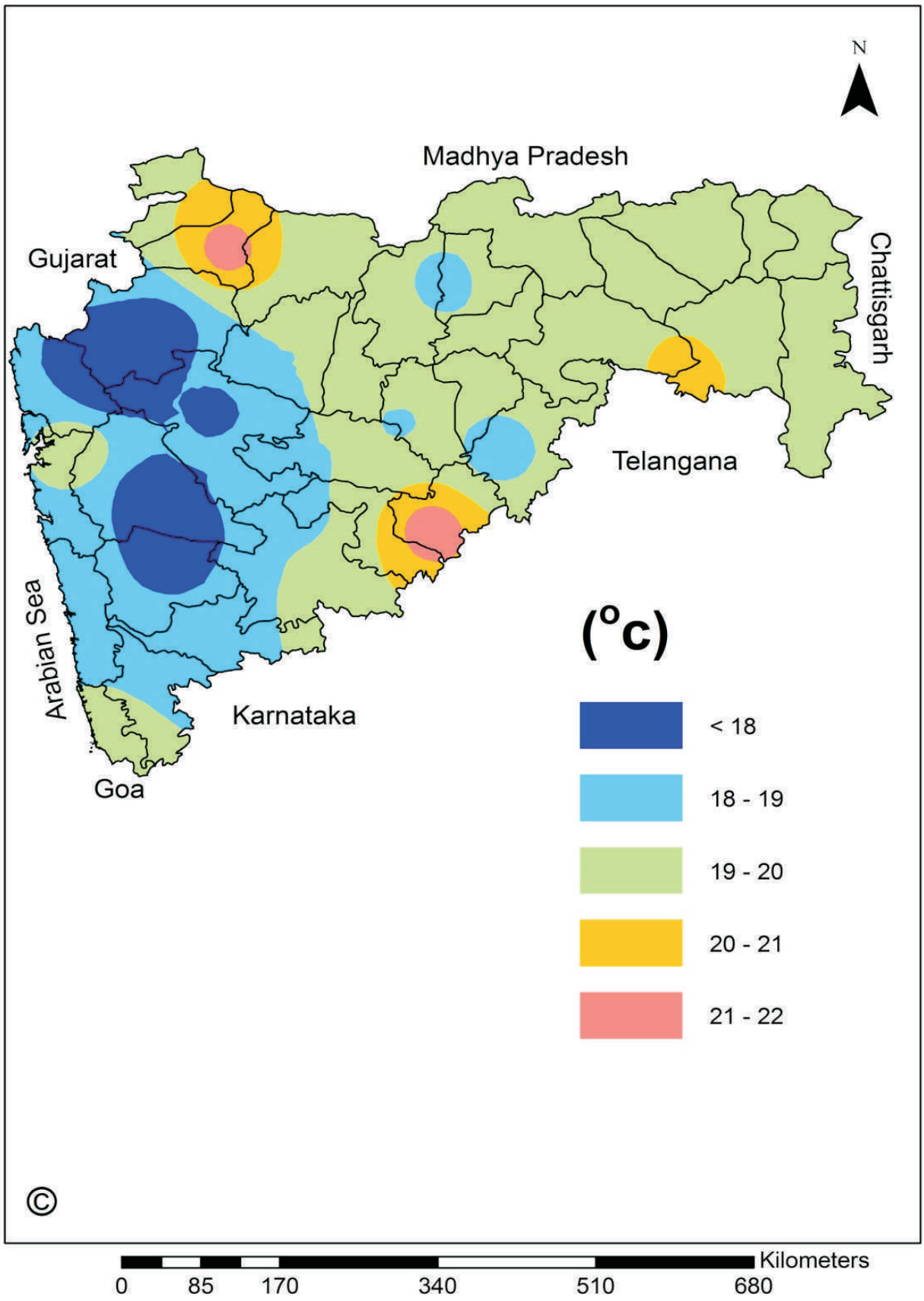

Fig. 98: Annual mean minimum temperatures in Maharashtra

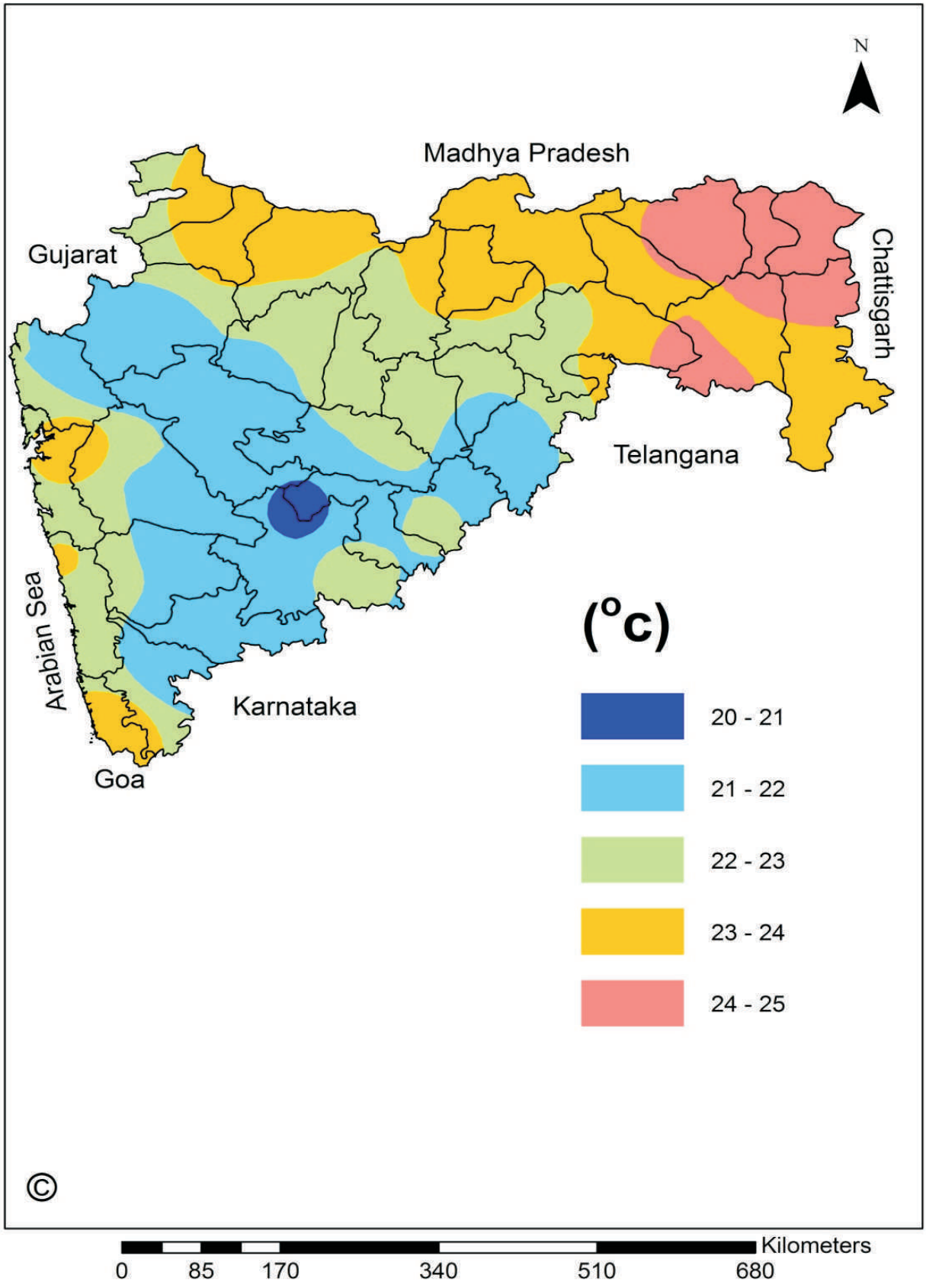

Fig. 99: Mean southwest monsoon season minimum temperature in Maharashtra

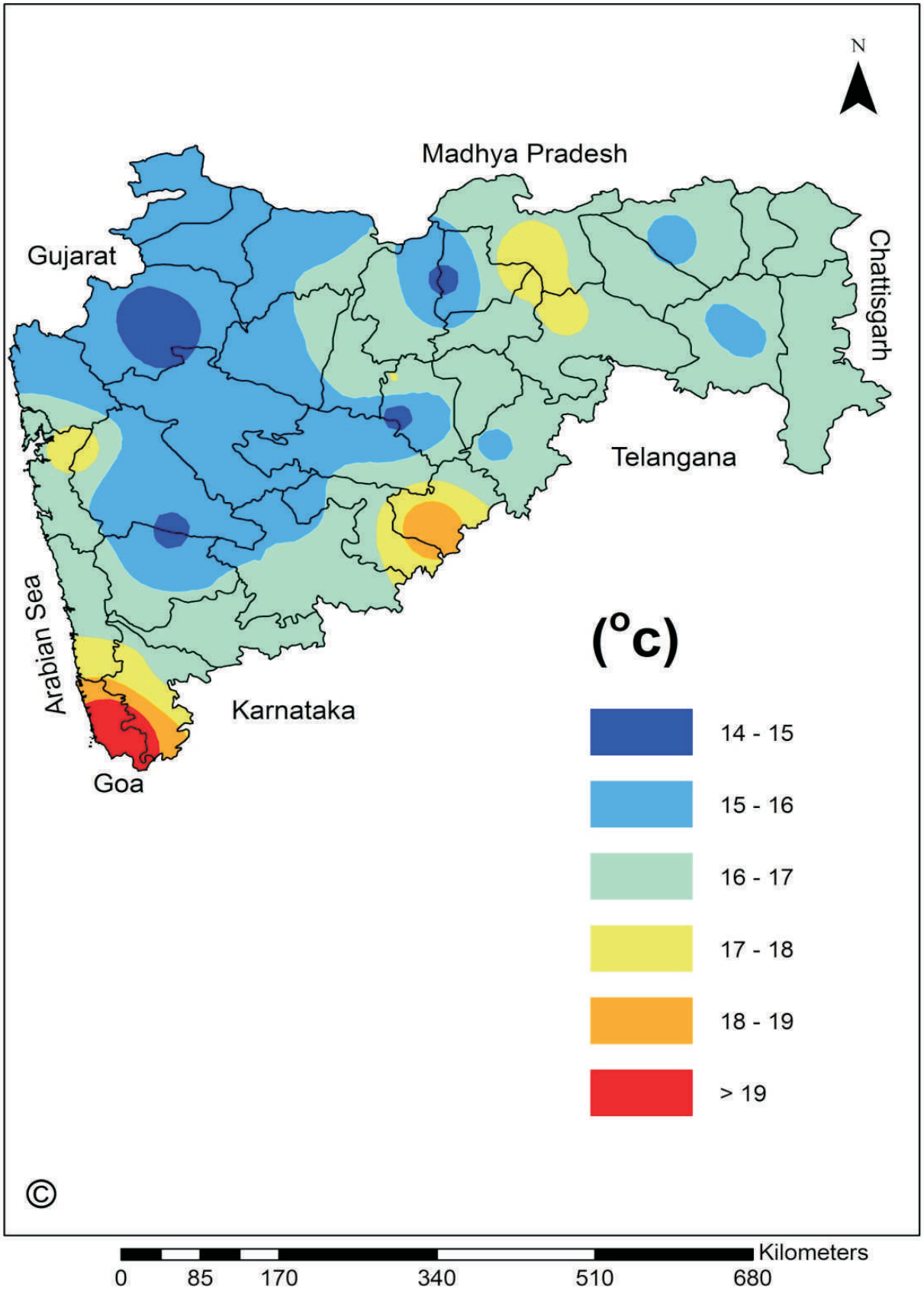

Fig. 100 : Mean post monsoon season minimum temperature in Maharashtra

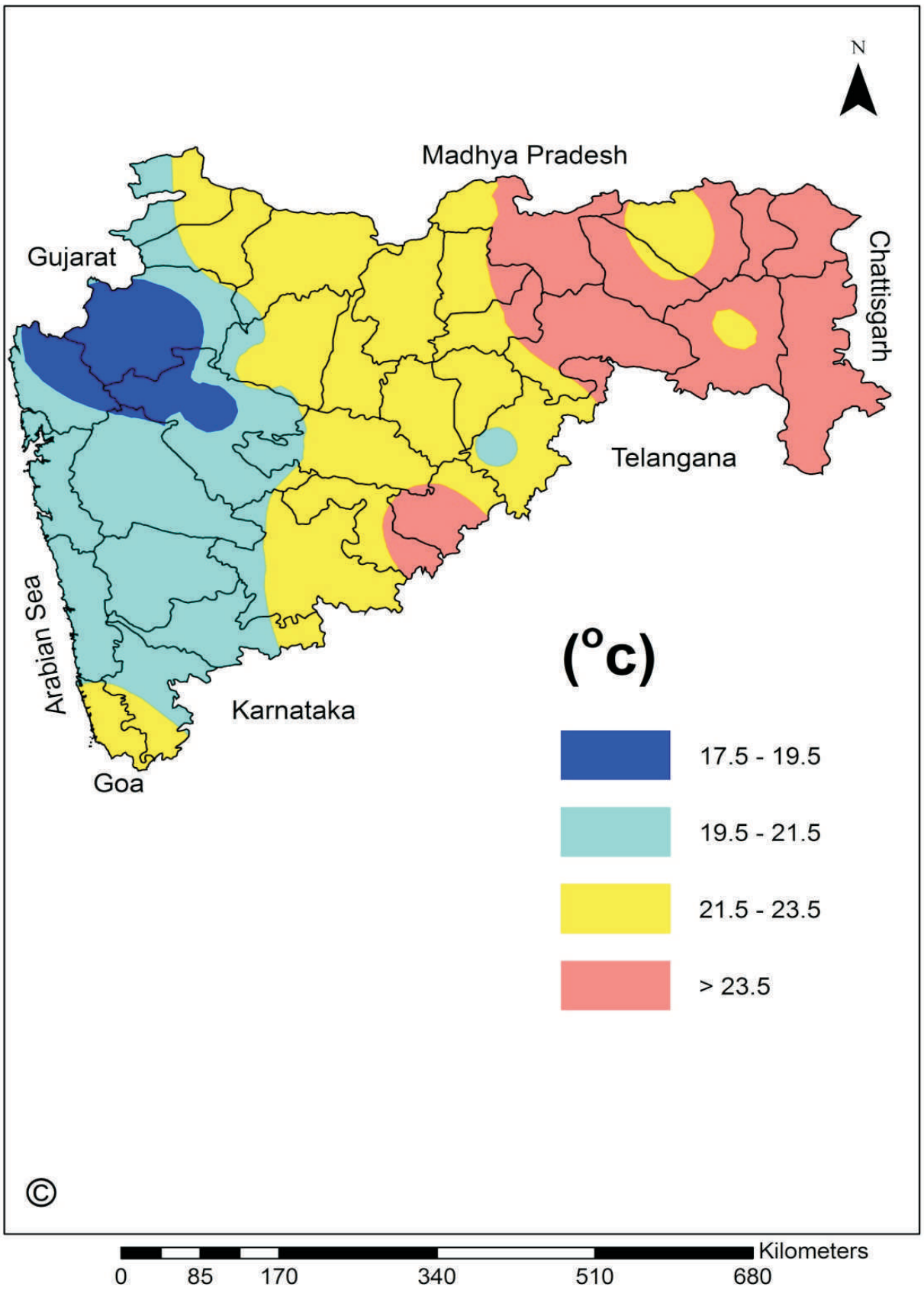

Fig. 101 : Mean summer season minimum temperature in Maharashtra

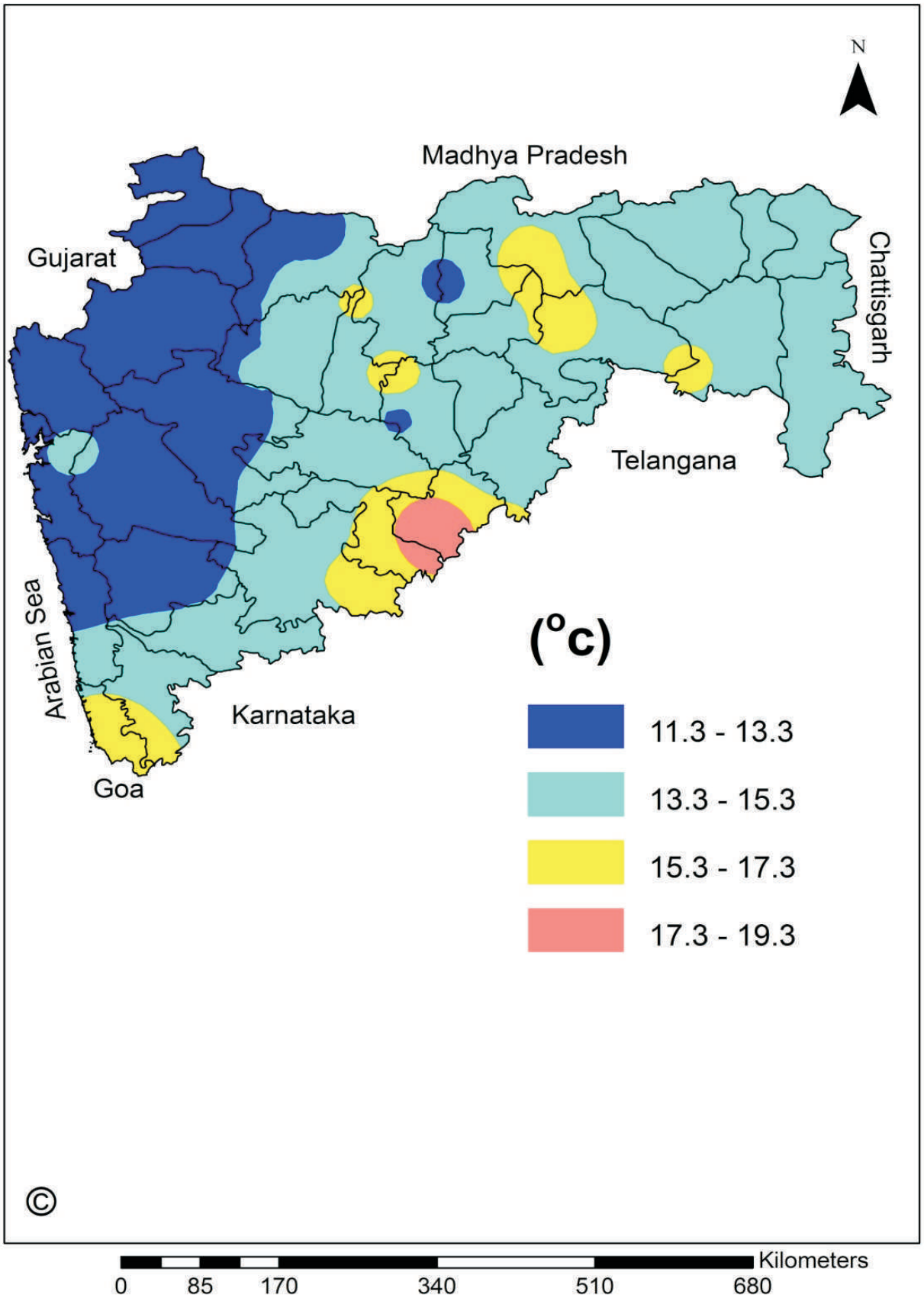

Fig. 102 : Mean winter season minimum temperature in Maharashtra

6. Relative Humidity

6.1. Morning Relative Humidity

On an annual basis the state of Maharashtra experiences 76% relative humidity in the morning. Regional differences exist (Fig. 103). In the *Konkan* region, the relative humidity is 89%. It is higher than the other three regions viz., *Marathwada* (67%), *Madhya Maharashtra* (80%) and *Vidarbha* (64%). *Vidarbha* lacks the data of eastern zone location which is comparatively more humid than west-central Vidarbha zones. Amongst the locations, Dapoli (92%), Kudal (89%), Jalgaon (89%),, Padegaon(88%) and Karjat (87%) are more humid. Marathwada and Vidarbha locations are least humid (Table. 26).

On monthly basis, state as a whole experiences high morning humidity during August (88%) and least humidity is recorded during April (59%). Regional differences do exist. The morning RH is different in various months. *Vidarbha* region is the least humid during summer months of April (37%), May (41%) and March (45%) compared to the other regions. Amongst the locations across different regions, Yavatmal (34%), Akola (37%), Nagpur (40%), Parbhani (44%), Dhule (47%), Osmanabad (48%) and Jalgaon (49%) are comparatively less humid during April. Higher humidity during this month is recorded in Dapoli (89%), Kudal (84%) and Karjat (78%).

During the SWM season the mean morning RH of the state is 85%. *Konkan* region records a higher value of 92%. Least morning RH prevails over Marathwada (79%) (Fig. 104). Amongst the district locations, Dapoli (94%), Igatpuri (94%), Kudal (93%), Kolhapur (93%), Padegaon (91%) and Karjat (90%), are the most humid, whereas Jalna (73%) followed by Nanded (75%), Yavatmal (77%) and Latur (78%) are least humid. During post monsoon season the mean morning RH of the state is 77%. Regional differences are similar to that of SWM season mean morning RH with *Konkan* recording higher value (90%) and the least morning RH prevailing over *Marathwada* region (Fig. 105). During the post monsoon season, Padegaon (93%), Dapoli (92%), Pune (90%), Karjat (89%) and Kudal (89%) experience higher morning humidity. Low morning humidity locations are Yavatmal (61%), Jalana (63%), Latur (64%), Nanded (65%), and Osmanabad (69%).

Summer is the season in Maharashtra during which lowest morning RH values (62%) are recorded. *Konkan* region experiences much higher morning RH (84%) as compared to *Madhya Maharashtra* (65%), *Marathwada* (54%) and *Vidarbha* (41%) (Fig. 106). In the high summer humidity Konkan region, Dapoli (89%) followed by Kudal (85%) tops the list. Lowest morning RH values are in Vidabha region at Yavatmal (37%) followed by Akola (42%) and Nagpur (43%). During the winter season, morning RH is more over the *Konkan* (89%) region followed by *Madhya Maharashtra* (75%), *Marathwada* (63%) and *Vidarbha* (62%) (Fig. 107). Dapoli (93%) and Padegaon (91%) are most humid, whereas Jalna and Yavatmal are the least humid (56%) places during winter.

6.2. Afternoon Relative Humidity

On an annual basis, afternoon relative humidity over Maharashtra is 47%. Regional differences however exist with Konkan region recording higher afternoon relative humidity (60%). *Madhya Maharashtra* and *Marathwada* are on par (46%) regarding annual afternoon relative humidity. *Vidarbha* region (40%) shows the least afternoon relative humidity. Amongst the district locations, Dapoli in *Konkan* has the highest afternoon RH of 66% and Akola in *Vidarbha* has the lowest afternoon RH of 35% (Fig. 108).

Mean monthly afternoon RH for the entire state shows that August (72%) month is most humid and April (29%) is the least humid. When different regions are compared Konkan region experiences high humid conditions across all the months (Table. 27). Vidarbha region is least humid during January (34%) to June (46%) and during the period from October to December compared to other regions. Marathwada is least humid during July to September. Highest humidity during April/May is noted at Dapoli (63%/64%) in Konkan and lowest at Akola (15%/19%) in Vidarbha.

During the SWM period the mean afternoon RH of the entire state is 66%, while *Konkan* region records the highest value of 82%, least afternoon RH prevails over *Marathwada* (61%) (Fig. 109). Amongst the locations, Dapoli and Igatpuri has an afternoon RH of 86% followed by Kudal (80%). These are most humid areas. Solapur (55%) followed by Rahuri, Dhule, Aurangabad, and Parbhani (56%) and Akola (57%) are the least humid areas. During post monsoon season, *Konkan* region continuous to be more humid with 54% afternoon humidity (Fig. 110). Dapoli experiences high afternoon humidity of (57%) followed by Kudal (54%). Driest district locations during the post monsoon season are Akola (33%), Dhule (33%), Jalgaon (38%), Nagpur (39%), Niphad (39%) and Rahuri (39%).

During summer season lowest afternoon relative humidity values are recorded as a mean for the entire state (31%). Region wise summer season afternoon RH averages 50% in *Konkan*, 32% in *Marathwada*, 28% in *Madhya Maharashtra* and 21% in *Vidarbha* (Fig. 111). Location wise Dapoli tops the list (61%) followed by Kudal (53%). Akola is the least humid with an afternoon RH of 17% followed by Parbhani (19%). During winter season, afternoon RH is higher over *Konkan* region (43%) compared to *Marathwada* (37%), *Madhya Maharashtra* (33%) and *Vidarbha* (31%) (Fig. 112). Across the state Dapoli (49%), Nanded (46%), Igatpuri (42%) and Kudal (41%) are the more humid areas during winter, whereas Akola (25%), Parbhani (28%), Dhule (28%) and Pune (29%) are the least humid.

Table. 26 : District wise average mean monthly and seasonal morning relative humidity (%)

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	PM
Dapoli	94	92	90	89	86	92	94	95	95	94	91	92	92	93	89	94	92
Karjat	88	84	77	78	78	86	92	93	90	91	89	87	86	86	78	90	89
Kudal	88	88	87	84	84	91	93	94	92	91	88	88	89	88	85	93	89
Average Konkan	**90**	**88**	**85**	**84**	**83**	**90**	**93**	**94**	**92**	**92**	**89**	**89**	**89**	**89**	**84**	**92**	**90**
Dhule	71	61	49	47	56	73	83	86	85	76	72	74	69	66	51	82	74
Jalgaon	67	59	50	49	61	74	84	88	85	71	64	67	89	63	54	83	67
Kolhapur	80	74	71	76	82	90	94	95	94	91	82	79	84	77	77	93	84
Igatpuri	70	66	59	64	79	91	97	96	92	78	67	67	77	68	67	94	71
Niphad	85	80	70	64	73	83	89	91	92	84	79	83	81	82	69	89	82
Padegaon	93	88	79	75	79	87	91	93	94	93	93	94	88	91	78	91	93
Pune	90	83	70	61	68	81	86	89	89	90	90	91	82	87	66	86	90
Rahuri	79	74	67	64	69	83	86	87	88	83	80	82	78	77	67	86	82
Solapur	69	57	49	51	62	80	85	87	87	80	74	71	71	63	54	85	75
Average Madhya Maharashtra	**78**	**71**	**63**	**61**	**70**	**82**	**88**	**90**	**90**	**83**	**78**	**79**	**80**	**75**	**65**	**88**	**80**
Aurangabad	70	64	57	56	67	81	87	89	88	78	72	70	73	67	60	86	73
Jalana	58	53	55	55	58	71	73	76	73	66	63	60	63	56	56	73	63
Latur	63	56	56	56	61	75	79	79	79	69	63	61	66	60	58	78	64
Nanded	66	59	55	53	51	65	76	79	79	67	64	63	65	63	53	75	65
Osmanabad	65	56	50	48	55	78	85	86	84	73	68	66	68	61	51	83	69
Parbhani	74	64	51	44	47	72	83	85	85	77	75	76	69	69	47	81	76
Average Marathwada	**66**	**59**	**54**	**52**	**57**	**74**	**81**	**82**	**81**	**72**	**68**	**66**	**67**	**63**	**54**	**79**	**68**
Akola	69	57	44	37	46	70	84	87	86	78	72	71	66	63	42	82	74
Nagpur	72	62	50	40	40	66	84	88	85	78	72	71	67	67	43	81	74
Yavatmal	59	53	40	34	37	63	82	84	79	68	59	57	60	56	37	77	61
Average Vidarbha	**67**	**57**	**45**	**37**	**41**	**66**	**83**	**86**	**83**	**75**	**68**	**66**	**64**	**62**	**41**	**80**	**70**
Average State	**75**	**69**	**62**	**59**	**65**	**79**	**86**	**88**	**87**	**80**	**75**	**75**	**76**	**72**	**62**	**85**	**77**

Table. 27 : District wise average mean monthly and seasonal afternoon relative humidity (%)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	PM
Dapoli	49	50	57	63	64	81	89	89	84	70	55	48	66	49	61	86	57
Karjat	40	35	32	35	44	69	84	85	78	62	47	43	54	38	37	79	51
Kudal	42	41	49	53	58	78	84	82	76	66	52	44	60	41	53	80	54
Average Konkan	**44**	**42**	**46**	**50**	**55**	**76**	**86**	**85**	**79**	**66**	**51**	**45**	**60**	**43**	**50**	**82**	**54**
Dhule	31	25	20	19	23	42	60	65	56	36	32	31	36	28	21	56	33
Jalgaon	36	30	25	22	26	45	65	70	60	41	37	37	60	33	24	60	38
Kolhapur	36	28	26	29	40	68	81	80	69	56	46	43	50	32	32	75	48
Igatpuri	44	40	36	39	52	79	91	90	83	63	49	47	59	42	42	86	53
Niphad	34	28	24	25	31	54	70	73	64	42	38	36	43	31	26	65	39
Padegaon	39	33	31	29	38	61	71	72	64	52	47	44	46	36	33	67	48
Pune	32	25	19	19	30	59	72	74	65	46	39	36	43	29	23	68	40
Rahuri	34	28	24	23	27	48	59	60	57	43	39	36	40	31	24	56	39
Solapur	36	31	27	23	27	46	56	59	56	47	39	36	40	34	26	55	41
Average Madhya Maharashtra	**36**	**30**	**26**	**25**	**33**	**56**	**69**	**71**	**64**	**47**	**41**	**38**	**46**	**33**	**28**	**65**	**42**
Aurangabad	40	36	31	28	31	44	59	61	58	45	41	40	43	38	30	56	42
Jalana	37	32	36	36	38	55	65	67	63	52	46	41	47	35	37	63	46
Latur	37	32	31	29	36	56	66	69	62	50	43	41	46	34	32	63	45
Nanded	45	46	45	41	37	52	64	65	64	56	51	46	51	46	41	62	51
Osmanabad	41	36	35	33	35	58	68	72	66	54	47	43	49	38	34	66	48
Parbhani	31	25	20	17	20	44	59	64	58	42	36	32	38	28	19	56	37
Average Marathwada	**39**	**35**	**33**	**31**	**33**	**52**	**64**	**66**	**62**	**50**	**44**	**41**	**46**	**37**	**32**	**61**	**45**
Akola	28	22	17	15	19	42	62	68	57	39	31	29	35	25	17	57	33
Nagpur	35	30	24	20	21	47	67	72	62	45	37	35	41	33	21	62	39
Yavatmal	38	32	25	21	24	49	71	76	68	54	45	41	45	35	24	66	47
Average Vidarbha	**34**	**28**	**22**	**19**	**21**	**46**	**67**	**72**	**62**	**46**	**38**	**35**	**40**	**31**	**21**	**62**	**40**
Average State	**37**	**33**	**30**	**29**	**34**	**56**	**70**	**72**	**65**	**51**	**43**	**39**	**47**	**35**	**31**	**66**	**44**

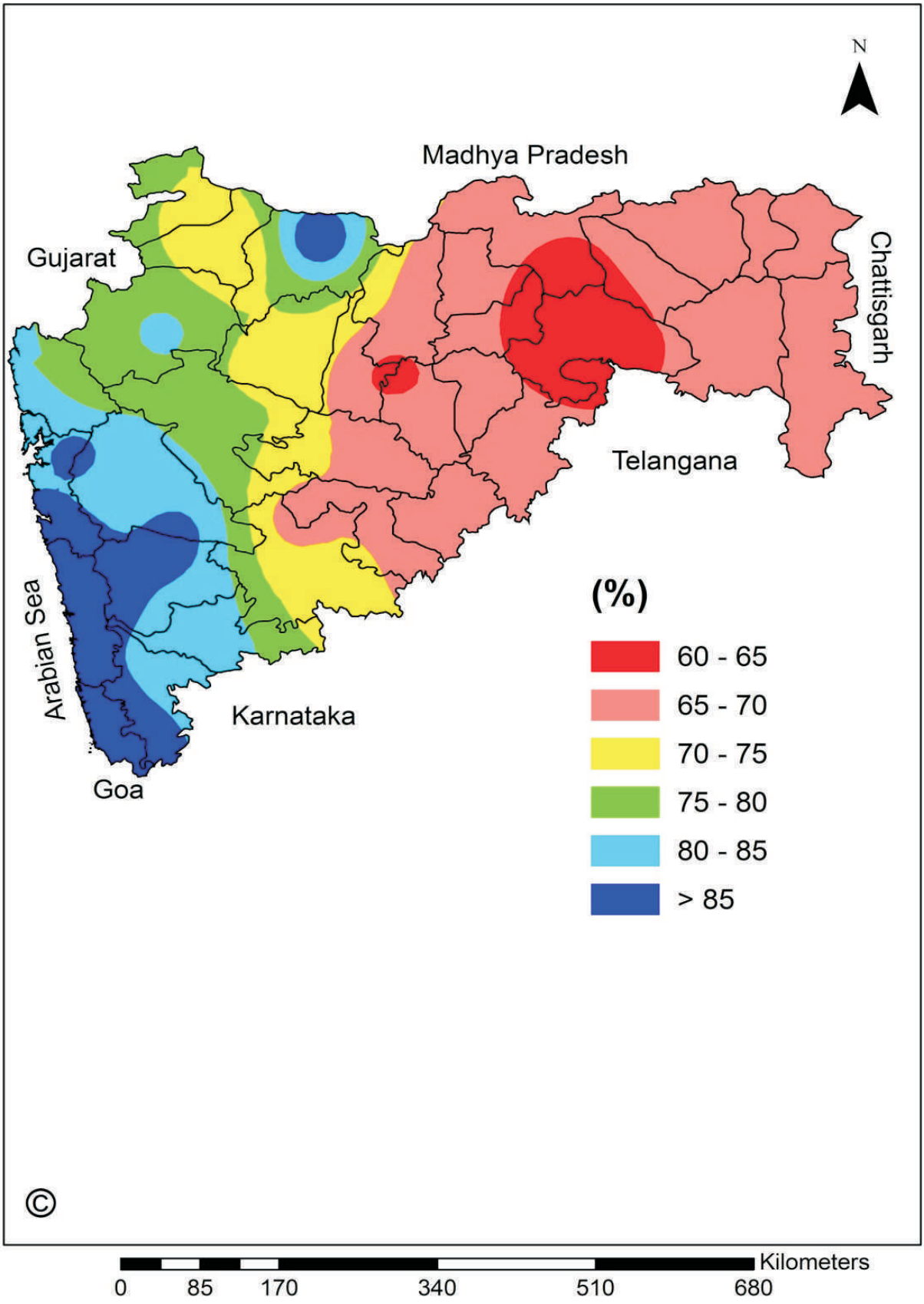

Fig. 103 : Mean annual morning relative humidity in Maharashtra

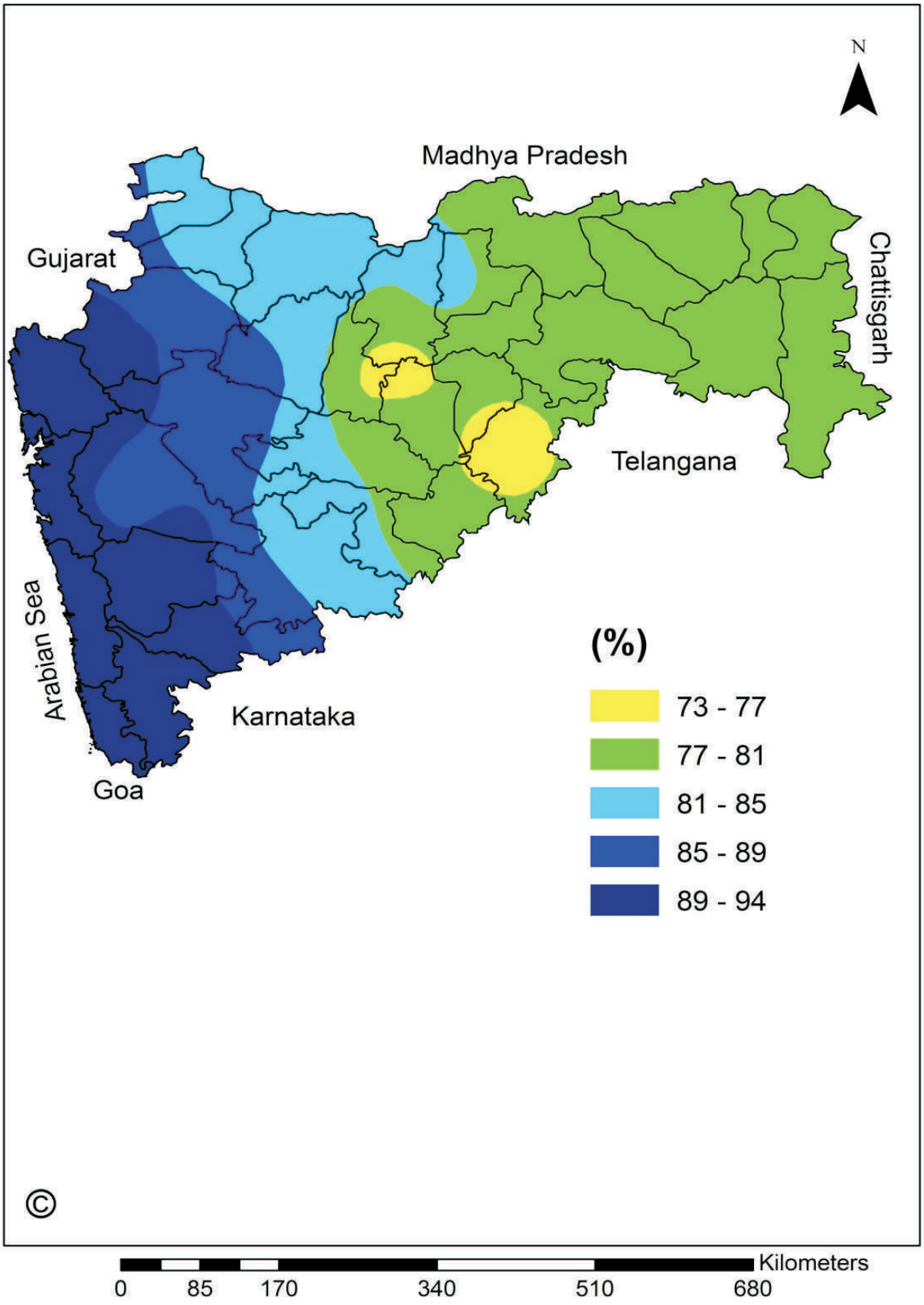

Fig.104 : Mean morning relative humidity during the southwest monsoon season in Maharashtra

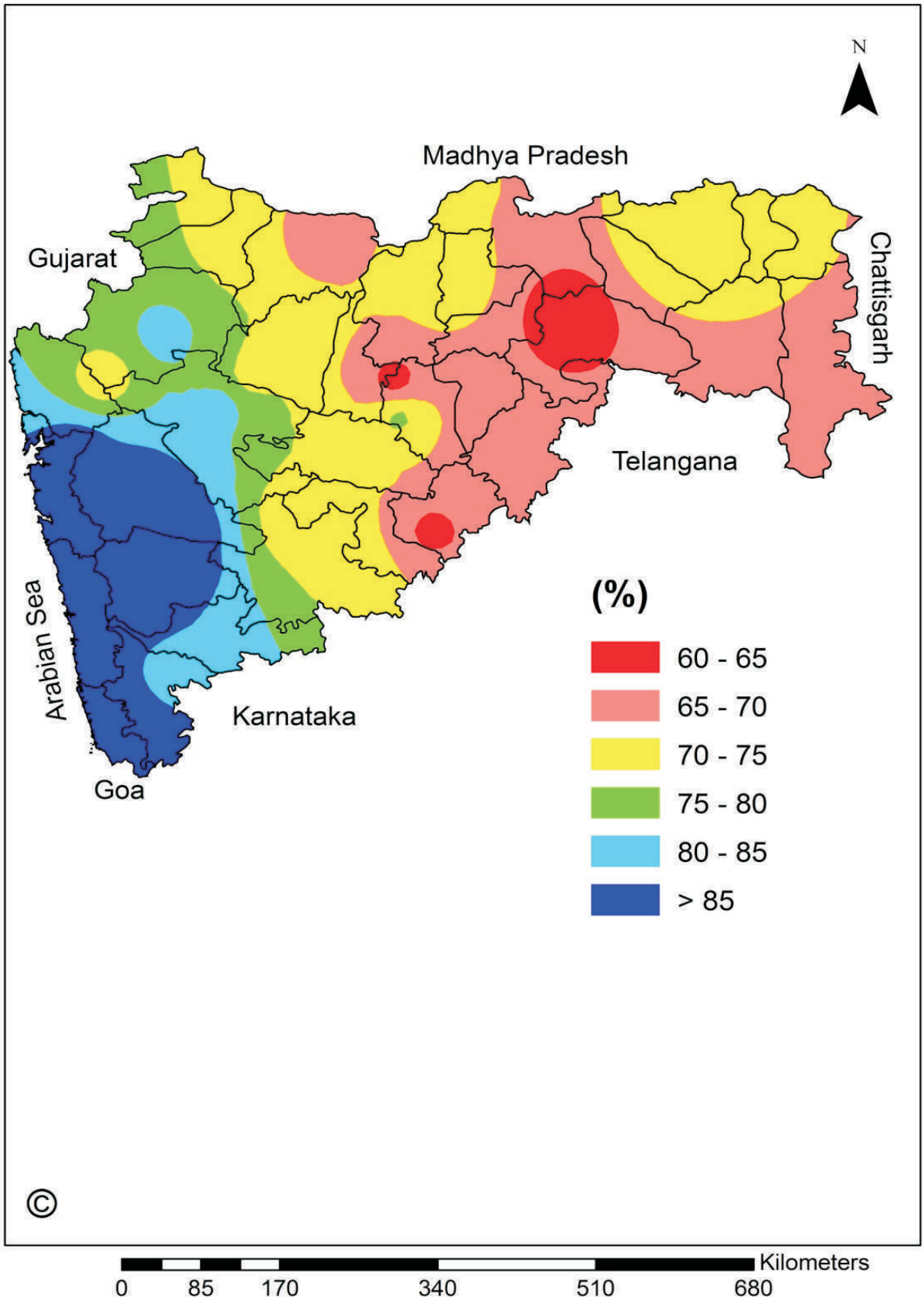

Fig. 105 : Mean morning relative humidity during the post monsoon season in Maharashtra

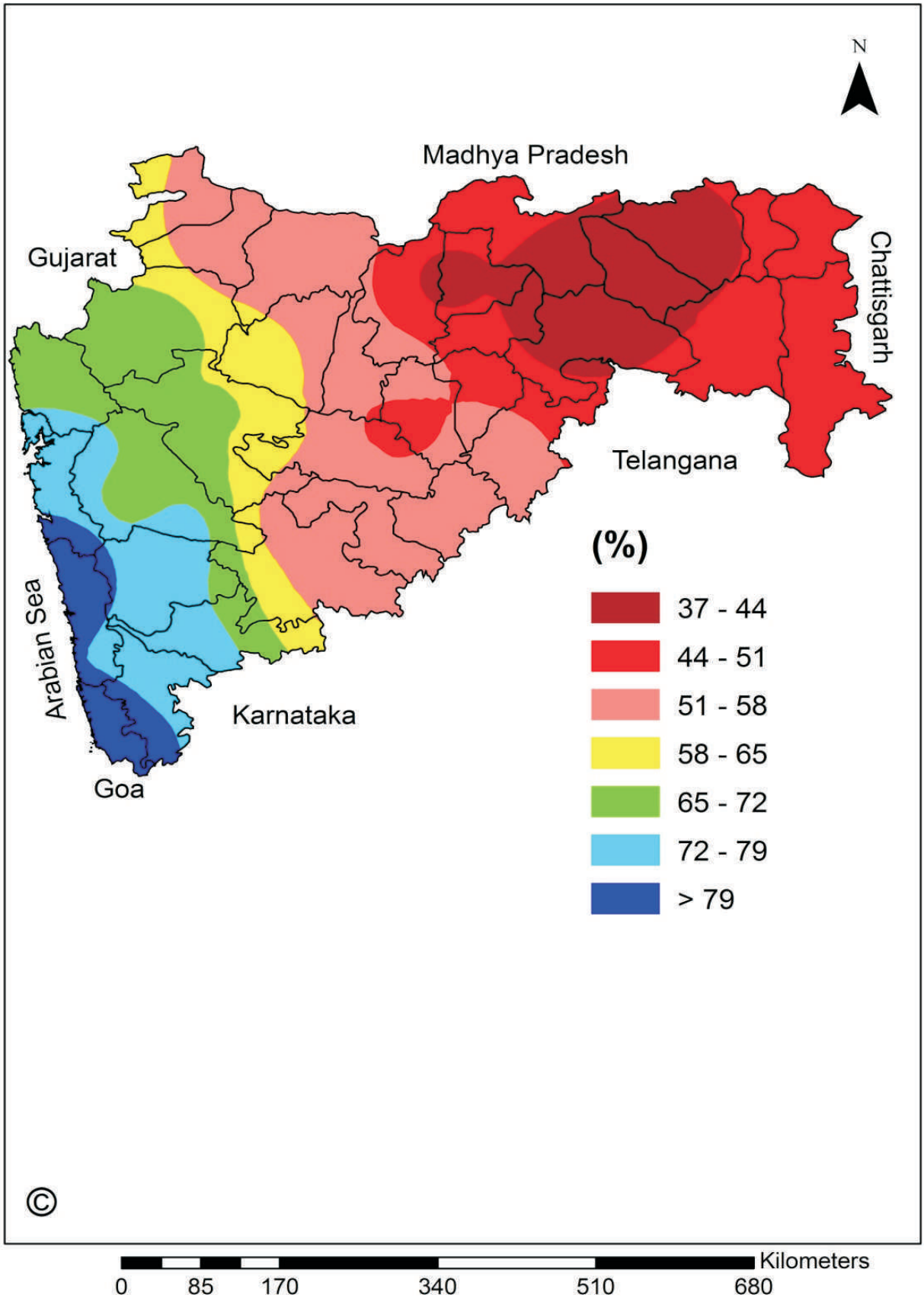

Fig. 106 : Mean morning relative humidity during the summer season in Maharashtra

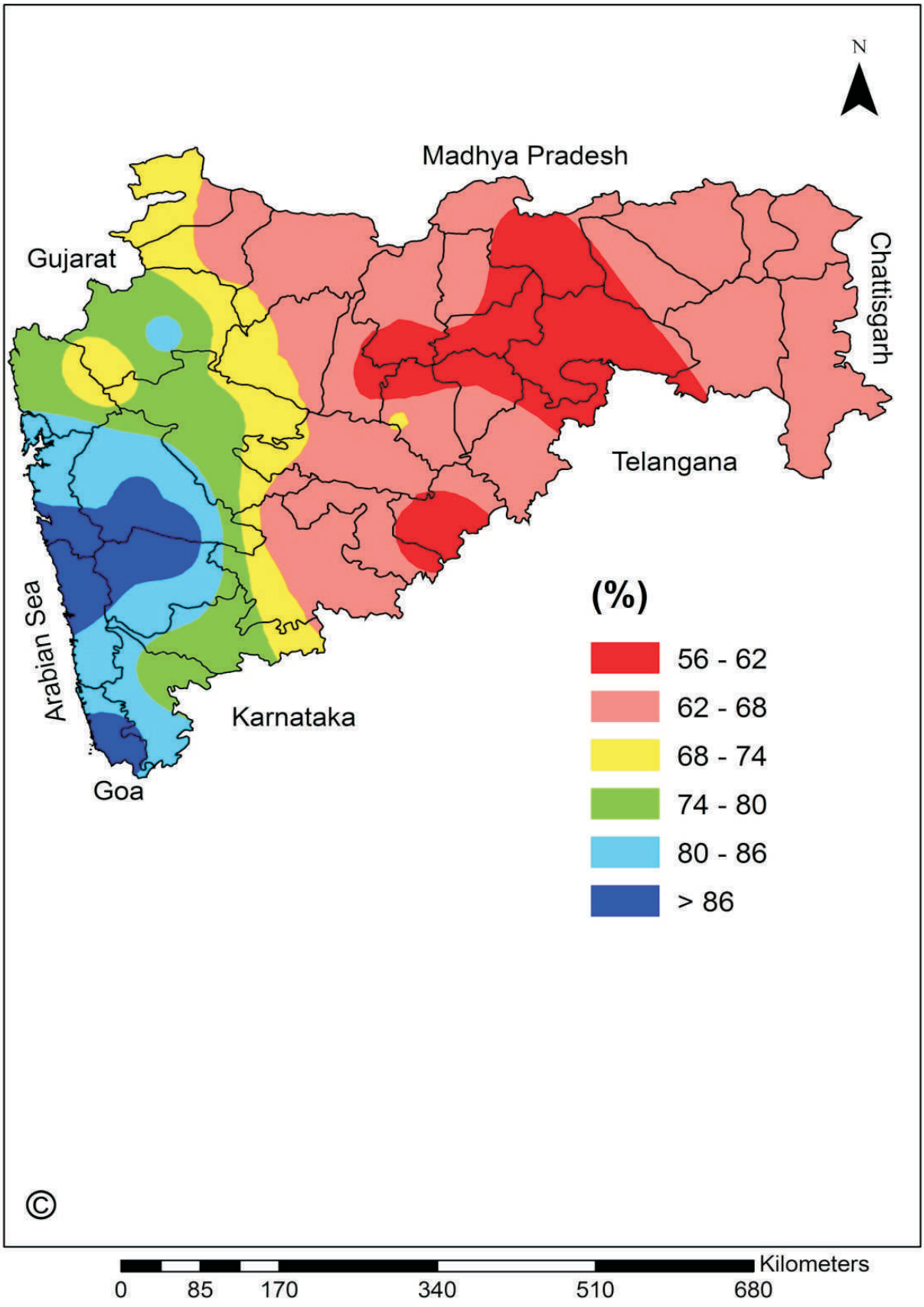

Fig. 107: Mean morning relative humidity during the winter season in Maharashtra

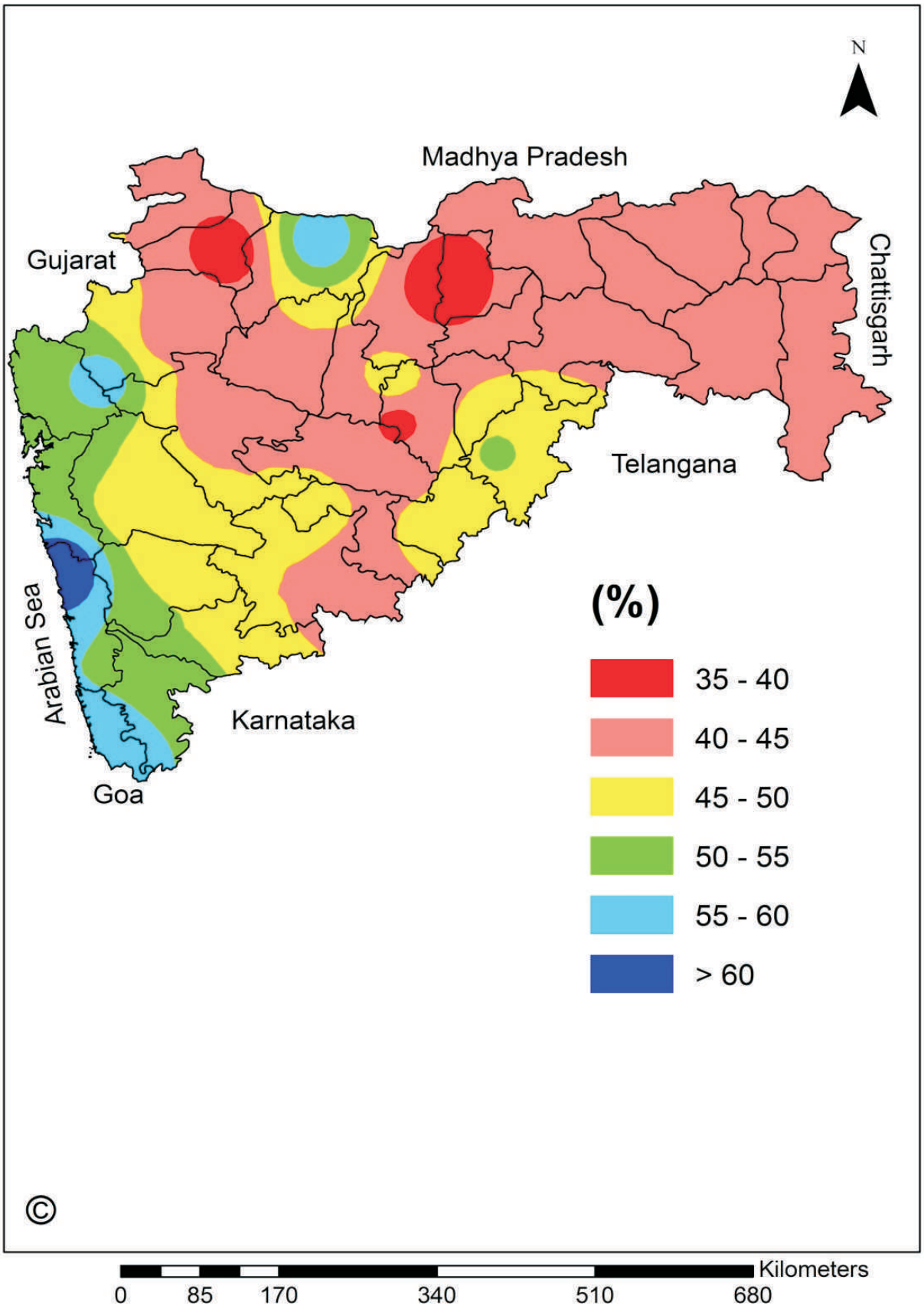

Fig. 108 : Annual mean relative humidity (afternoon) over Maharashtra

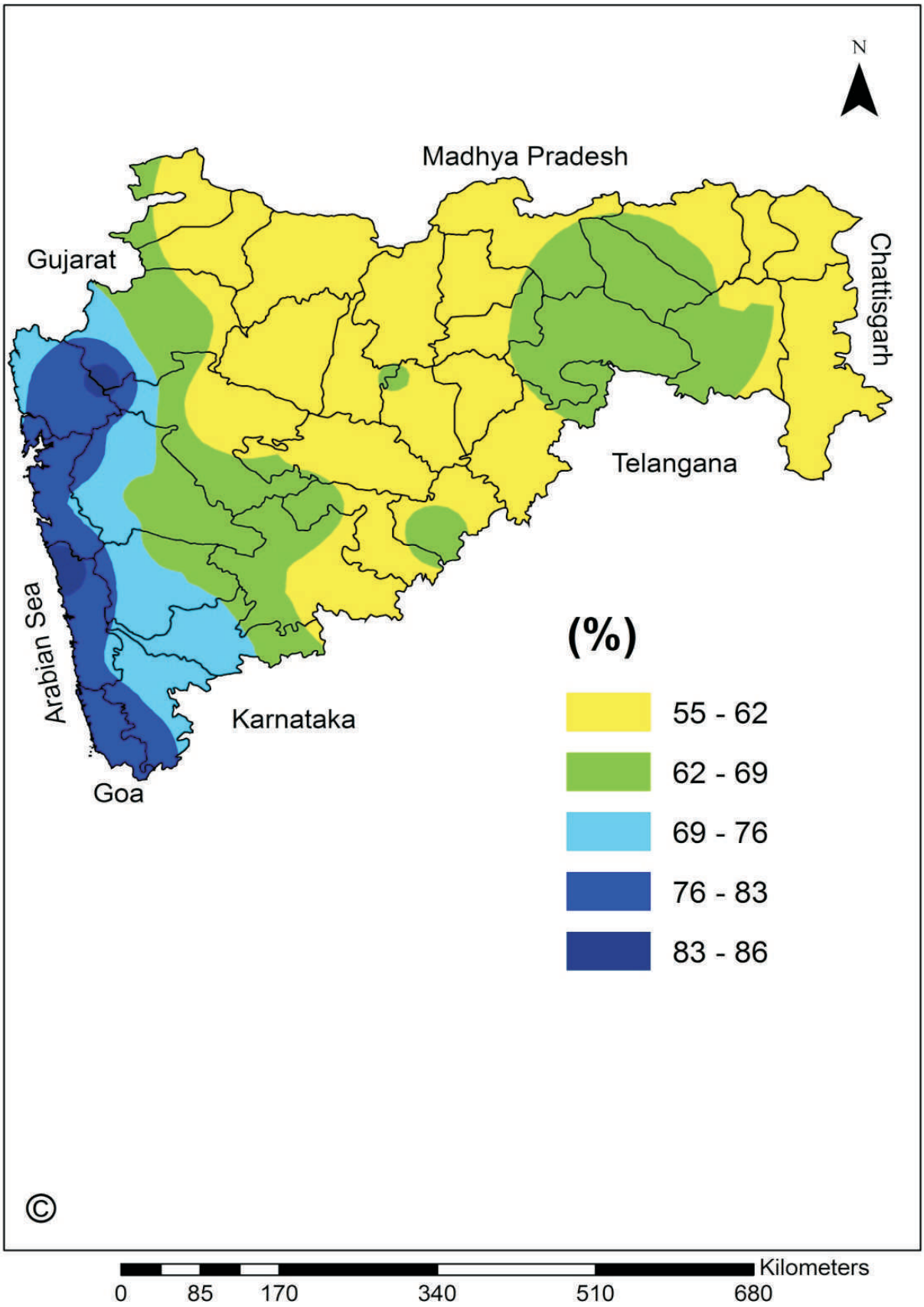

Fig. 109 : Mean southwest monsoon season relative humidity (afternoon) over Maharashtra

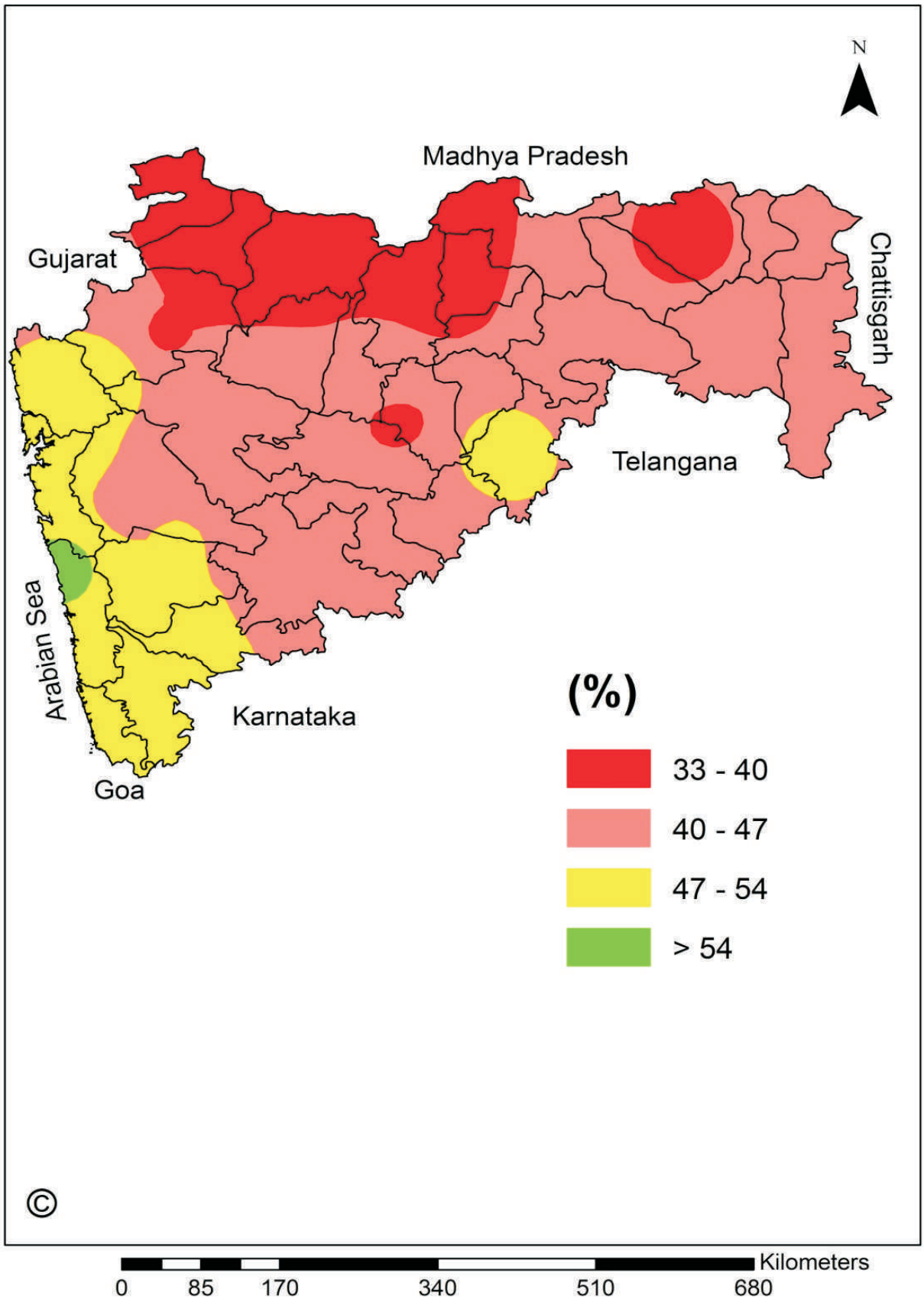

Fig. 110 : Mean post monsoon season relative humidity (afternoon) over Maharashtra

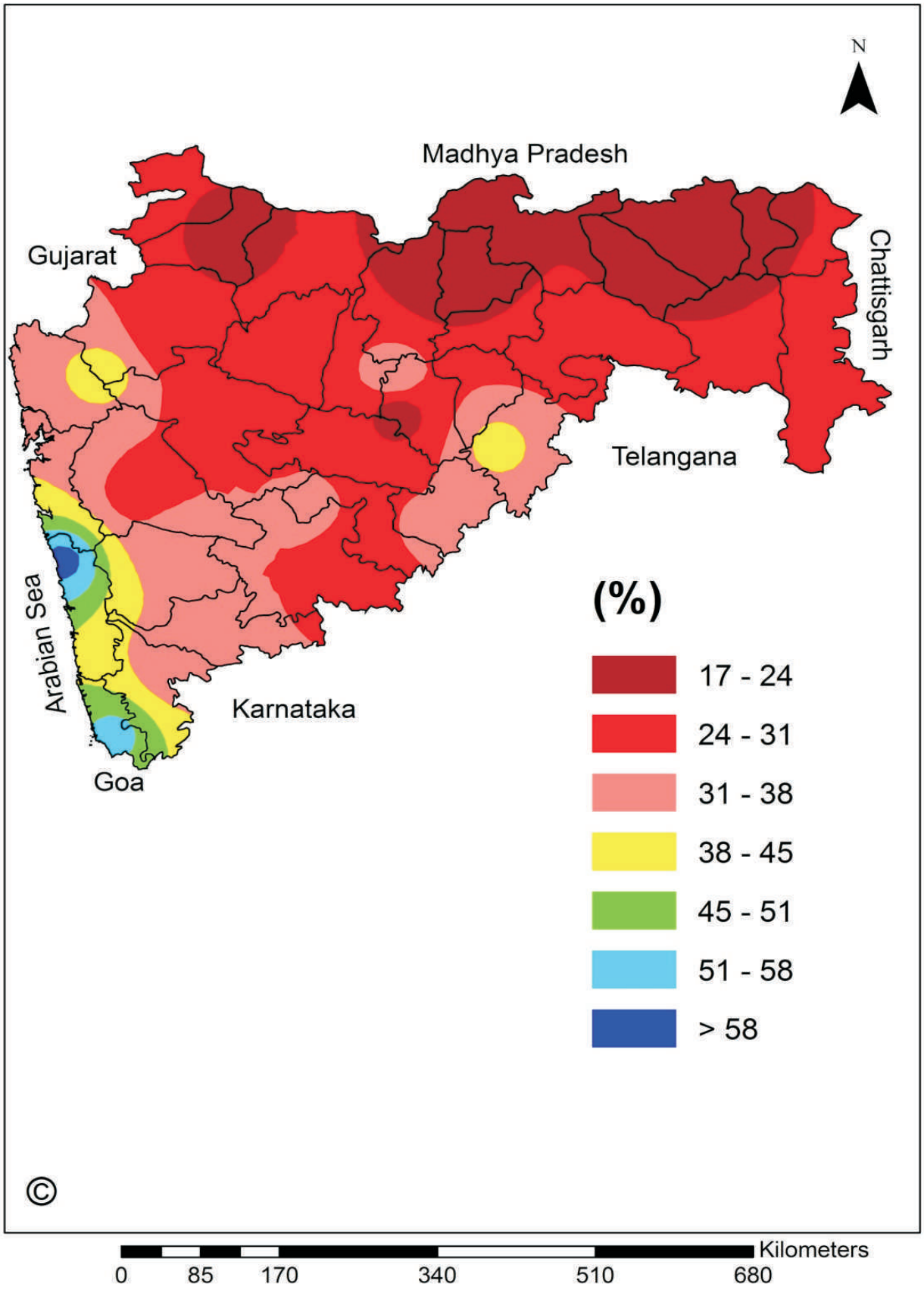

Fig. 111 : Mean summer season relative humidity (afternoon) over Maharashtra

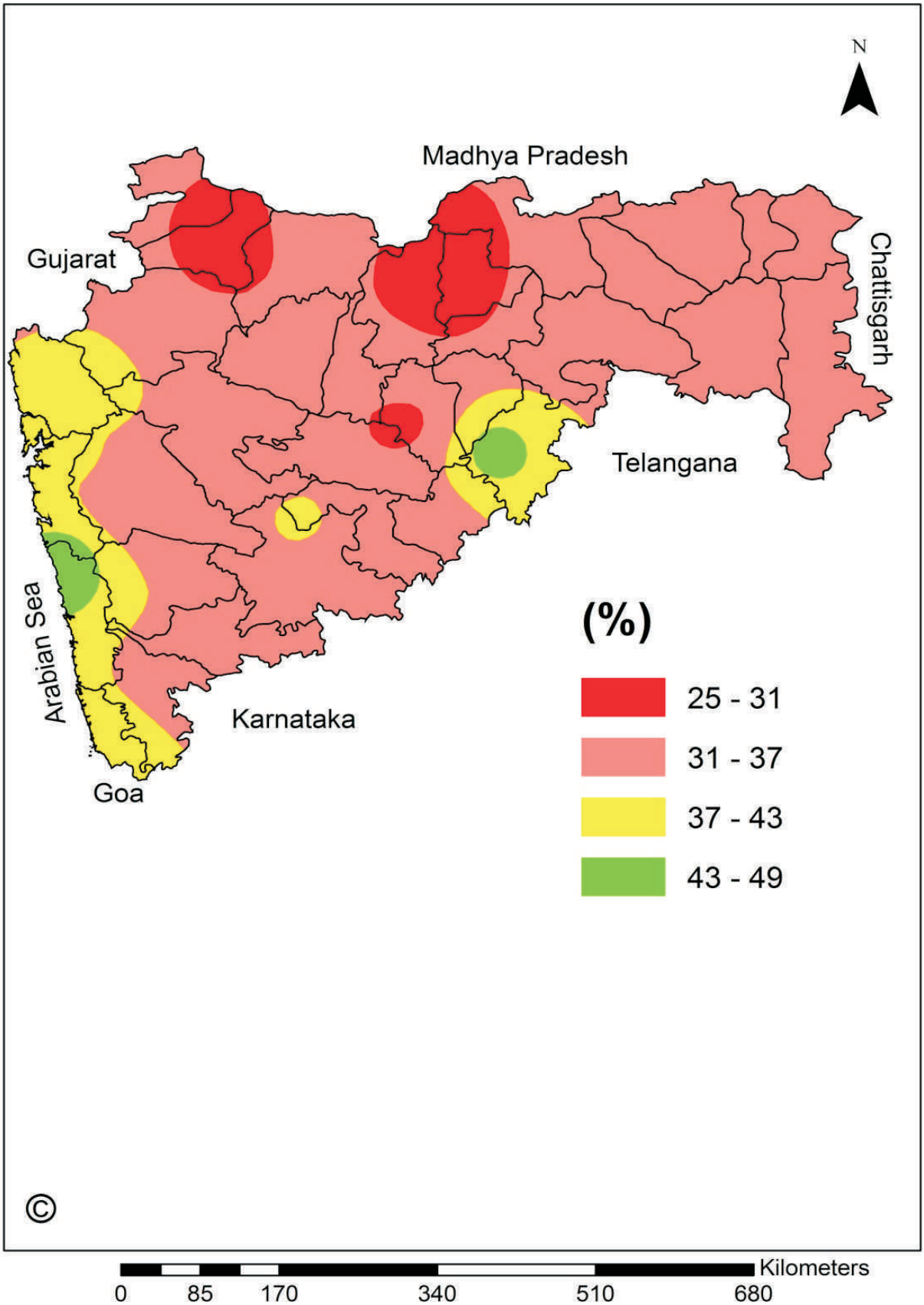

Fig. 112 : Mean winter season relative humidity (afternoon) over Maharashtra

7. Wind Speed

The mean annual wind speed for the entire state is 6.0 kmph with *Madhya Maharashtra* region recording highest average wind speed of 7.4 kmph. The spatial distribution of annual wind speed (Fig. 113) shows a range of 2.4 to 14.9 kmph across various state locations. Coastal *Konkan* region is relatively calm with an average wind speed of 3.7 kmph. Annual wind speed averages 5.5 kmph for *Vidarbha* and 5.0 kmph for *Marathwada* regions. On an annual basis location wise more windy conditions prevail over Jalgaon (14.9 kmph) in *Madhya Maharashtra* and relatively calm conditions are observed at Kudal (2.4 kmph) in *Konkan* region (Table 28).

June is the month with high wind conditions for the entire state (9.3 kmph); and *Madhya Maharashtra* region during this month experiences high wind speeds with Jalgaon recording the highest wind speed of 21.1 kmph. In other regions, Akola (13.5 kmph) in *Vidarbha*, Parbhani (10.6 kmph) in *Marathwada* and Dapoli (7.2 kmph) in *Konkan* are the maximum wind speed locations in respective region during the month of June. Kudal in *Konkan* experiences lowest June windiness (3.5 kmph).

Wind speeds during SWM period range on an average between 4.9 to 9.1 kmph for the four different regions with a mean value of 7.5 kmph for the state (Fig. 114). Jalgaon (17.0 kmph) and Sholapur (10.1 kmph) in *Madhya Maharashtra* and Akola (10.4 kmph) in *Vidarbha* region are the locations with high windiness, whereas Kudal (3.0 kmph) in *Konkan* and Aurangabad in *Marathwada* (3.9 kmph) has calm conditions during SWM period. Compared to SWM season, wind speeds during post monsoon season are almost one half (4.1 kmph) (Fig. 115). Winds over *Madhya Maharashtra* region (5.2 kmph) are relatively strong compared to other regions (2.3 to 3.8 kmph) with Jalgaon registering higher wind speeds (111.3 kmph). Winds over *Konkan* region (2.3 kmph) are relatively calm with Kudal (1.5 kmph), recording lowest wind speed during post monsoon season.

Winds during summer season (7.0 kmph) are stronger than those during the post monsoon season for the state as a whole. Strong winds prevail over *Madhya Maharashtra* (8.7 kmph) followed by *Vidarbha* (6.6 kmph), Marathwada (5.5 kmph) and *Konkan* (4.4 kmph) regions (Fig. 116). Wind speeds are highest (18.3 kmph) over Jalgaon followed by Padegaon (9.5 kmph) in Madhya Maharashtra. Wind speeds range between 8.2 to 8.9 kmph in Solapur, Dhule and Akola. In *Konkan* region having lowest windiness, Kudal records the least wind speed (3.0 kmph). During winter season also the winds are stronger than post monsoon season. Region wise wind speeds are higher across *Madhya Maharashtra* (5.5 kmph) followed by *Marathwada* (4.1 kmph), *Vidarbha* (4.0 kmph) and *Konka*n (2.6 kmph). Jalgaon experiences strong winds (10.9 kmph) followed by Padegaon (9.3 kmph) in *Madhya Maharashtra* (Fig. 117). *Konkan* locations are calm (1.9 to 3.3 kmph) during winter season.

Table. 28 : District wise average mean monthly and seasonal wind speed (kmph)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	PM
Dapoli	3.0	3.7	4.4	5.5	6.4	7.2	8.6	7.0	4.0	2.9	2.6	2.6	4.8	3.3	5.4	6.7	2.7
Karjat	2.4	2.9	3.6	4.9	6.1	6.0	5.4	4.5	4.1	3.5	2.6	2.5	4.0	2.7	4.9	5.0	2.8
Kudal	1.6	2.3	2.7	3.1	3.3	3.5	3.7	2.8	1.9	1.5	1.4	1.4	2.4	1.9	3.0	3.0	1.5
Average Konkan	**2.3**	**3.0**	**3.6**	**4.5**	**5.3**	**5.6**	**5.9**	**4.8**	**3.3**	**2.6**	**2.2**	**2.2**	**3.7**	**2.6**	**4.4**	**4.9**	**2.3**
Dhule	4.2	5.2	6.4	8.5	11.4	10.3	7.9	6.6	5.8	4.4	3.9	3.7	6.5	4.7	8.8	7.6	4.0
Jalgaon	10.1	11.7	14.1	17.9	23.0	21.1	17.0	15.5	14.6	12.8	11.2	10.0	14.9	10.9	18.3	17.0	11.3
Kolhapur	3.4	4.0	5.1	6.2	8.4	9.1	9.0	6.5	4.3	2.5	3.3	3.8	5.4	3.7	6.5	7.2	3.2
Igatpuri	4.7	4.9	4.9	5.3	7.8	7.8	7.8	6.5	4.5	3.9	4.7	4.2	5.5	4.8	6.0	6.7	4.3
Niphad	3.0	3.6	4.2	6.6	10.9	11.4	10.4	8.6	5.8	4.0	3.6	2.7	6.2	3.3	7.2	9.1	3.4
Padegaon	9.1	9.6	9.5	9.6	9.5	6.1	4.0	4.3	6.3	7.7	8.4	8.7	8.0	9.3	9.5	5.2	8.3
Pune	2.8	3.7	4.6	6.2	9.6	10.8	10.7	9.1	6.1	3.5	3.2	2.9	6.1	3.2	6.8	9.2	3.2
Rahuri	3.6	4.2	4.8	6.4	9.1	11.5	11.5	10.1	6.4	4.2	4.0	3.5	6.6	3.8	6.8	9.9	3.9
Solapur	5.3	5.9	6.4	7.7	10.4	12.4	11.9	9.7	6.5	5.0	5.3	4.7	7.6	5.6	8.2	10.1	5.0
Average Madhya Maharashtra	**5.1**	**5.9**	**6.7**	**8.3**	**11.1**	**11.2**	**10.0**	**8.5**	**6.7**	**5.3**	**5.3**	**4.9**	**7.4**	**5.5**	**8.7**	**9.1**	**5.2**
Aurangabad	3.7	3.8	3.7	3.5	4.8	5.4	4.4	3.5	2.3	2.7	3.7	3.7	3.7	3.8	4.0	3.9	3.4
Parbhani	4.0	4.7	5.3	6.3	9.3	10.6	9.4	8.1	5.8	4.4	4.3	3.7	6.3	4.3	7.0	8.5	4.1
Average Marathwada	**3.9**	**4.3**	**4.5**	**4.9**	**7.1**	**8.0**	**6.9**	**5.8**	**4.1**	**3.6**	**4.0**	**3.7**	**5.0**	**4.1**	**5.5**	**6.2**	**3.8**
Akola	4.2	5.0	6.0	7.9	12.9	13.5	11.1	9.9	6.8	3.7	3.5	3.4	7.3	4.6	8.9	10.4	3.6
Sindewahi	3.9	4.7	5.0	5.5	6.0	6.4	5.1	4.5	3.4	3.1	3.2	3.3	4.5	4.3	5.5	4.9	3.2
Nagpur	2.9	3.6	3.8	5.0	7.3	7.8	6.7	6.0	4.5	3.2	2.9	2.6	4.7	3.2	5.4	6.2	2.9
Average Vidarbha	**3.7**	**4.4**	**4.9**	**6.1**	**8.7**	**9.2**	**7.6**	**6.8**	**4.9**	**3.3**	**3.2**	**3.1**	**5.5**	**4.0**	**6.6**	**7.2**	**3.2**
Average State	**4.2**	**4.8**	**5.5**	**6.7**	**9.0**	**9.3**	**8.4**	**7.1**	**5.4**	**4.2**	**4.2**	**3.9**	**6.0**	**4.5**	**7.0**	**7.5**	**4.1**

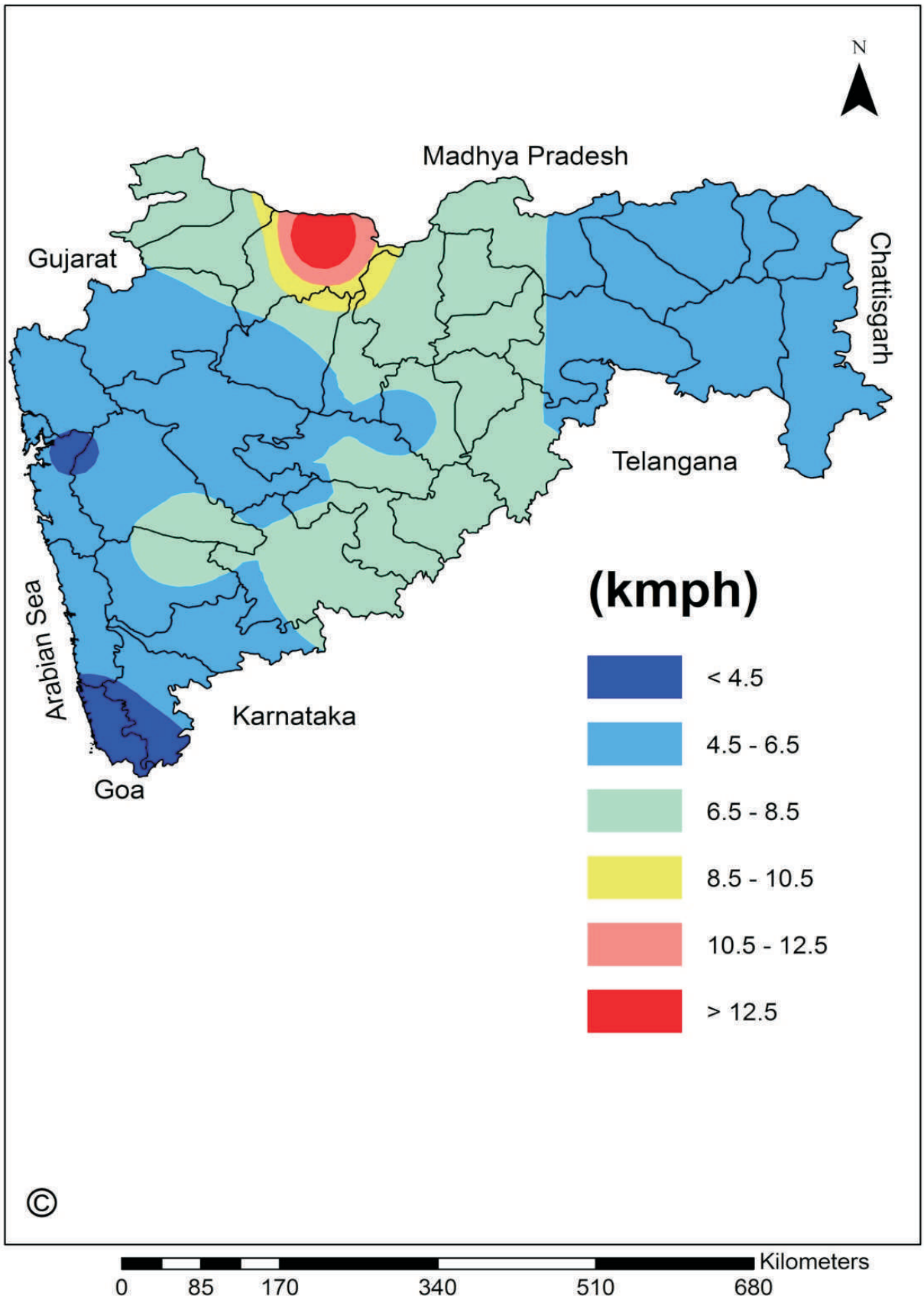

Fig. 113: Annual mean wind speed over Maharashtra

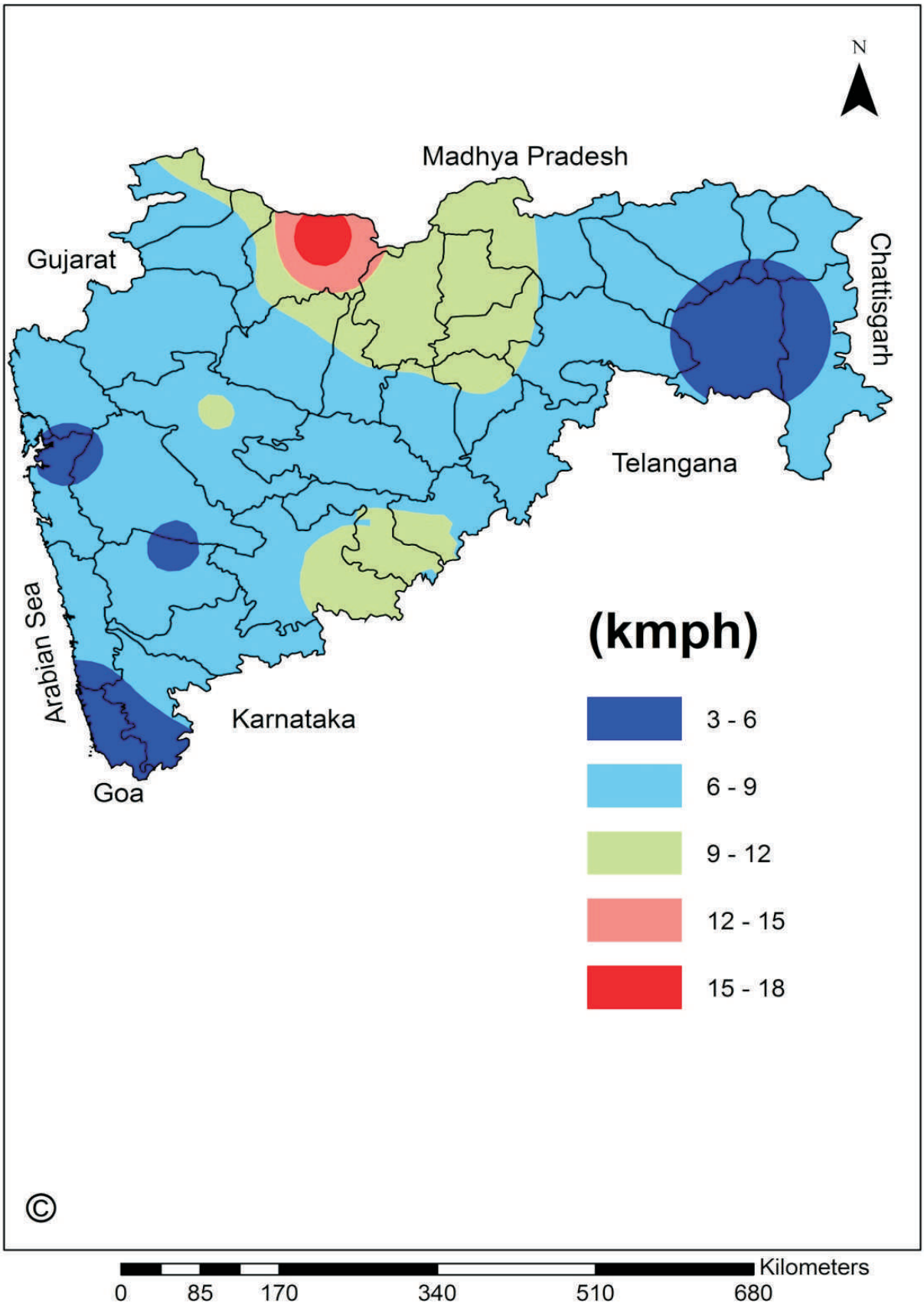

Fig. 114: Southwest monsoon season mean wind speed over Maharashtra

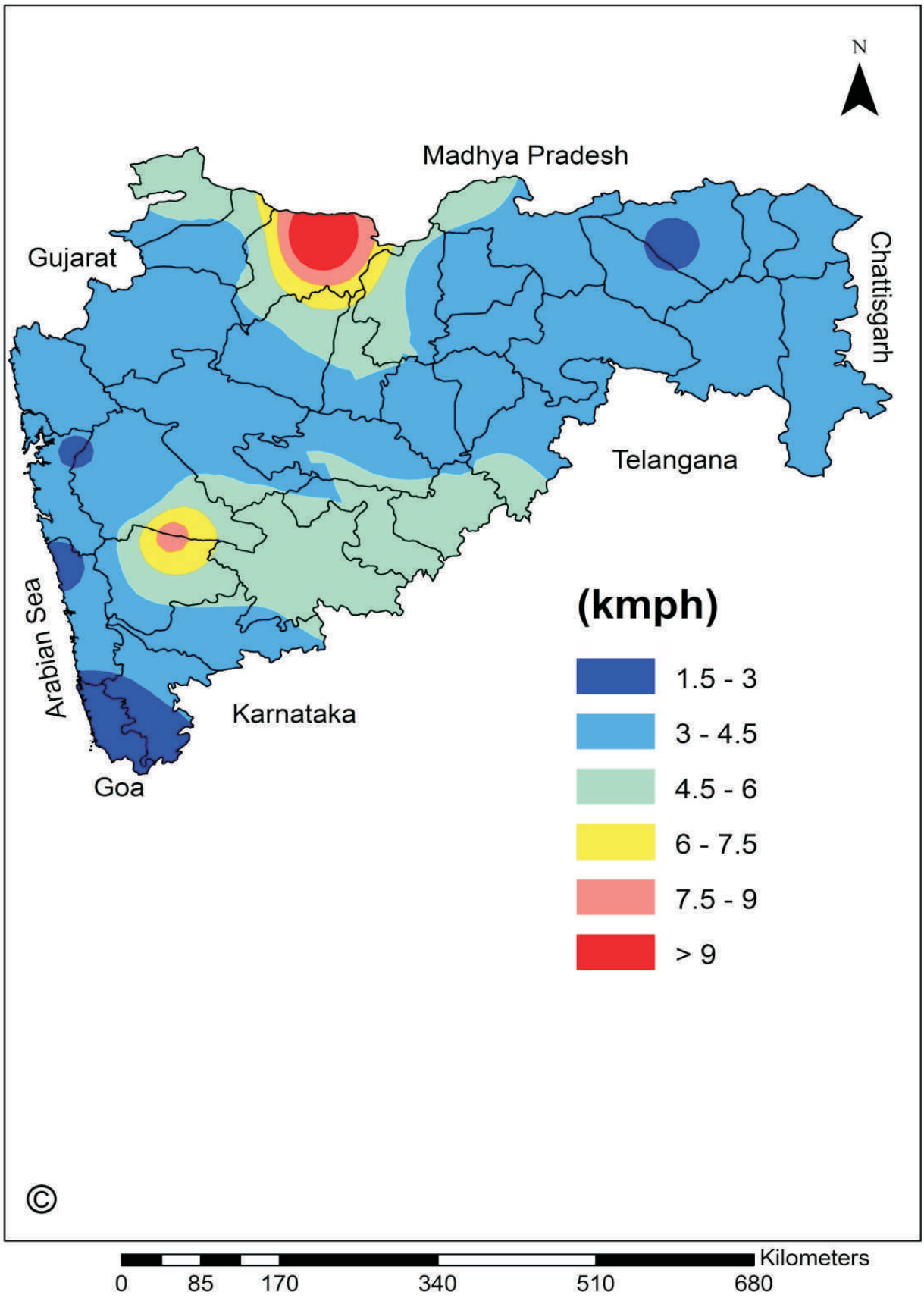

Fig. 115: Post monsoon season mean wind speed over Maharashtra

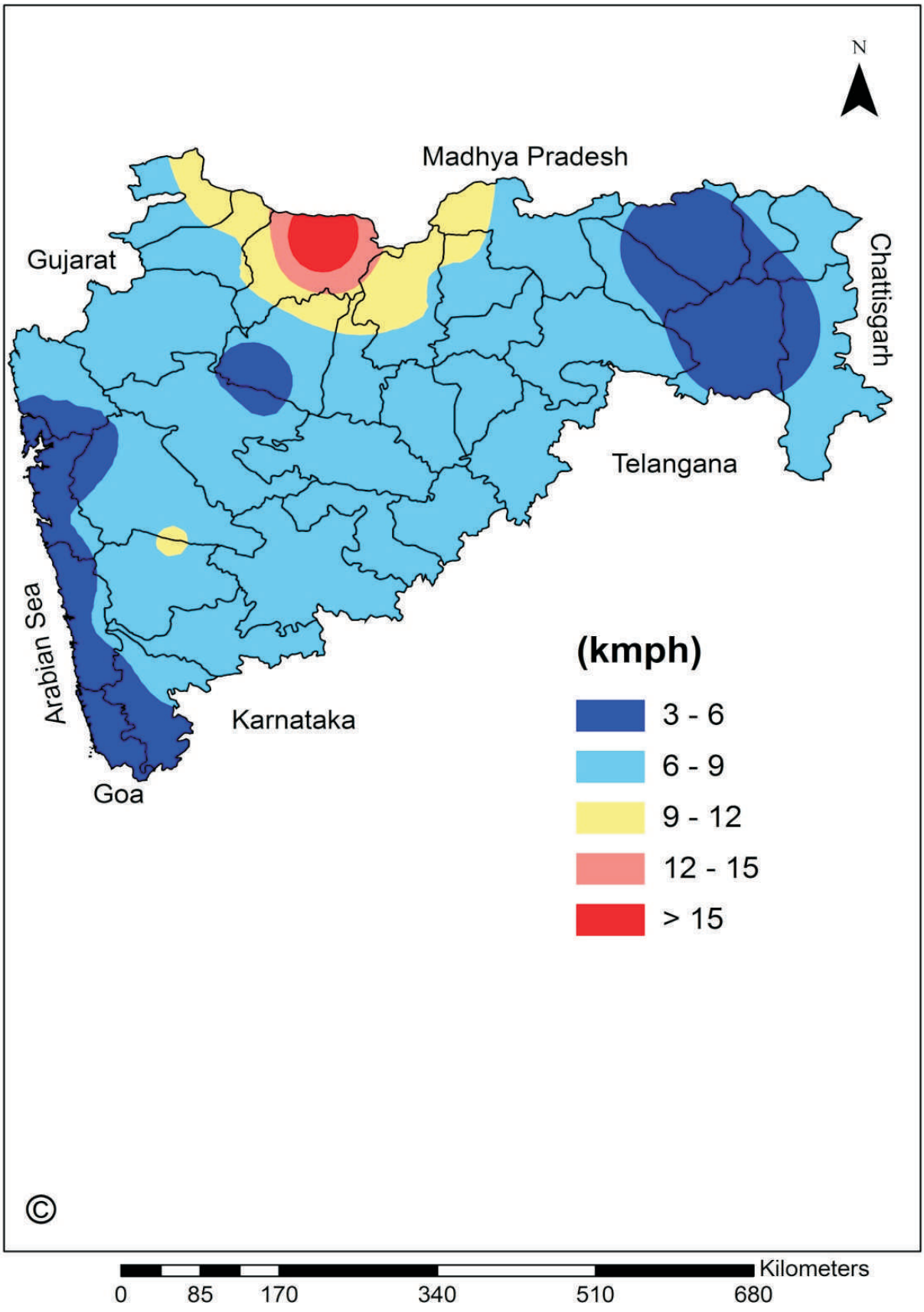

Fig. 116 : Summer season mean wind speed over Maharashtra

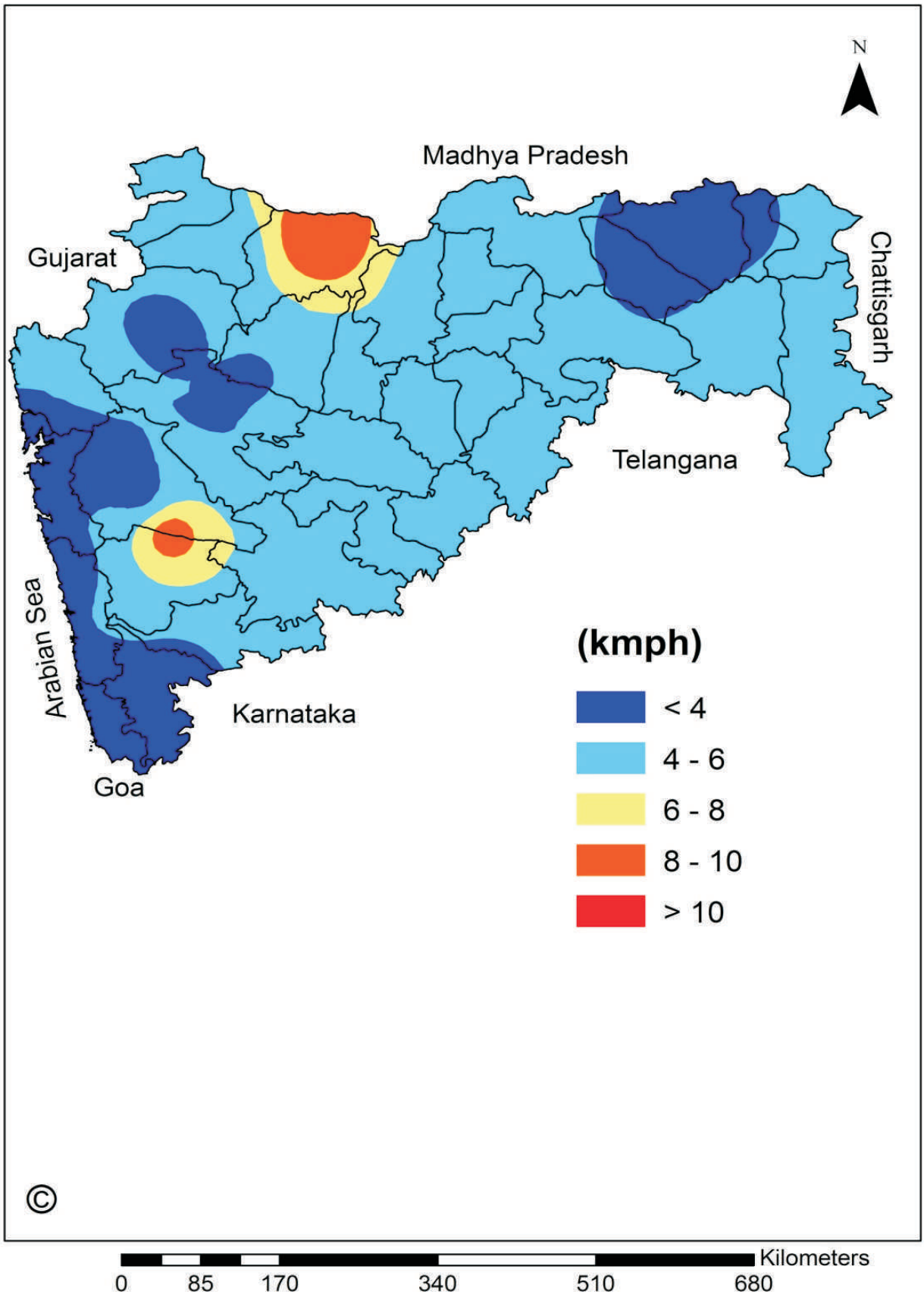

Fig. 117 : Winter season mean wind speed over Maharashtra

8. Sunshine Hours

Mean annual number of hours of bright sunshine for the state are 7.2 hrs/day with *Marathwada (*7.8 hrs/day) receiving sunlight for a longer period followed by *Vidarbha* (7.4 hrs/day), *Madhya Maharashtra* (7.3 hrs/day) and *Konkan* (6.5 hrs/day) (Fig. 118). Parbhani (8.5 hrs/day) in *Marathwada* region is the brightest location and Karjat (6.2 hrs/day) in *Konkan* region is the dimmest .State basis April month has longer sunshine hours (9.5 hrs/day) and July is the month with minimum sunshine hours (3.0 hrs/day). Region wise *Konkan* experiences longer sunshine hours in February month whereas in the remaining three regions April month has longer sunshine hours. In *Marathwada* May month also has equally longer sunshine hours (10.2 hrs/day) as April. Parbhani district location receives sunshine hours for the longest period (10.6 hrs/day) in the month of April. In *Madhya Maharashtra* region, Niphad (10.4 hrs/day), Jalgaon (10.3 hrs/day) and Pune (10.0 hrs/day) are the brightest locations in May month. Igatpuri receives sunlight for the shortest period of 0.7 hrs/day in the month of July (Table. 29).

Of all the four seasons, SWM season receives sun light for the shortest period (4.2 hrs/day). *Konkan* region records the lowest number of hours/day of bright sunlight (3.0 hrs) among the four regions (Fig. 119). Location wise Parbhani (5.8 hrs/day), Akola (5.1 hrs/day), Jalgaon (5.1 hrs/day) and Dhule (5.0 hrs/day) have sunshine for longer duration during SWM season while Igatpuri (2.0 hrs/day) and Karjat (2.5 hrs/day) the least. Compared to SWM season, the hours of sunshine during a day are high (8.0 hrs/day) during post monsoon season for the state as a whole. *Marathwada* region receives on an average sunlight for 8.5 hrs/day followed by Vidarbha (8.1 hrs/day), *Madhya Maharashtra* (8.0 hrs/day) and Konkan (7.5 hrs/day) regions (Fig. 120). Parbhani (9.3 hrs/day) receives bright sunlight for a longer period, and Dhule for the shortest period (6.3 hrs/day) during the post monsoon season.

Summer season experiences longest sunshine hours (9.4 hrs/day) on the state as a whole. Summers have longer sunshine hours over *Marathwada* region (10.0 hrs/day) compared to the other three regions (8.6 to 9.6 /day) (Fig. 121). Parbhani (10.5 hrs/day), Jalgaon (10.1 hrs/day) and Niphad (10.1 hrs/day) have longer days during summer. Across the remaining locations, sunshine hours are in the range of 8.5 to 9.8 hrs/day during summer. During winter season also *Marathwada* region experiences longer sunshine hours (9.6 hrs/day) compared to the remaining three regions (8.5 to 8.9 hrs/day) (Fig. 122). Parbhani in *Marathwada* (10.0 hrs/day) followed by Niphad (9.7 hrs/day) in *Madhya Maharashtra* regions have longer sunlight hours while Dhule (6.8 hrs/day) in *Madhya Maharashtra* experiences winter sunlight for short periods. Across the remaining locations, sunshine hours vary from 8.3 to 9.7 hrs/day during winter.

Table. 29 : District wise annual, monthly and seasonal mean sunshine hours/day

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	PM
Dapoli	8.5	9.0	8.7	9.0	8.7	4.2	2.2	2.7	4.5	6.7	8.1	8.1	6.7	8.8	8.8	3.4	7.6
Karjat	7.9	8.7	8.3	8.6	8.5	3.4	1.3	1.8	3.6	6.6	7.9	7.7	6.2	8.3	8.5	2.5	7.4
Kudal	8.7	9.4	8.6	9.0	8.2	3.7	1.8	2.6	4.4	6.5	7.8	8.3	6.7	9.1	8.6	3.1	7.5
Average Konkan	**8.4**	**9.0**	**8.5**	**8.9**	**8.5**	**3.8**	**1.8**	**2.4**	**4.2**	**6.6**	**7.9**	**8.0**	**6.5**	**8.7**	**8.6**	**3.0**	**7.5**
Dhule	6.1	7.6	9.2	9.3	9.3	7.2	4.2	3.7	5.1	6.5	6.4	5.9	6.5	6.8	9.3	5.0	6.3
Jalgaon	8.7	9.5	9.8	10.2	10.3	6.7	3.8	3.7	6.3	8.6	8.7	8.6	7.9	9.1	10.1	5.1	8.6
Kolhapur	8.9	9.8	9.4	9.4	9.3	5.3	2.9	3.1	5.1	6.6	7.9	8.2	7.1	9.3	9.4	4.1	7.6
Igatpuri	8.7	8.8	8.9	9.3	8.1	3.2	0.7	0.8	3.2	6.7	8.6	9.0	6.3	8.7	8.8	2.0	8.1
Niphad	9.4	10.0	9.8	10.0	10.4	6.9	3.7	3.5	5.9	8.1	9.0	9.1	7.9	9.7	10.1	5.0	8.7
Pune	9.0	9.8	9.4	9.9	10.0	6.1	3.6	3.6	5.5	7.6	8.4	8.8	7.6	9.4	9.8	4.7	8.3
Rahuri	8.8	9.4	9.5	9.9	9.6	6.0	3.8	4.1	5.9	7.9	8.1	8.8	7.6	9.1	9.7	4.9	8.3
Solapur	9.0	9.5	9.4	9.4	9.1	5.9	3.9	4.1	5.7	7.5	8.2	8.8	7.5	9.3	9.3	4.9	8.1
Average Madhya Maharashtra	**8.6**	**9.3**	**9.4**	**9.7**	**9.5**	**5.9**	**3.3**	**3.3**	**5.3**	**7.4**	**8.2**	**8.4**	**7.3**	**8.9**	**9.6**	**4.5**	**8.0**
Aurangabad	8.9	9.5	8.9	9.7	10.0	5.6	2.3	3.0	5.2	7.5	8.2	7.4	7.1	9.2	9.5	4.0	7.7
Parbhani	9.7	10.3	10.4	10.6	10.3	7.1	4.7	4.7	6.8	8.9	9.3	9.5	8.5	10.0	10.5	5.8	9.3
Average Marathwada	**9.3**	**9.9**	**9.7**	**10.2**	**10.2**	**6.4**	**3.5**	**3.9**	**6.0**	**8.2**	**8.8**	**8.5**	**7.8**	**9.6**	**10.0**	**4.9**	**8.5**
Akola	8.3	8.8	9.1	9.4	9.4	6.6	4.0	3.7	6.2	8.0	8.3	8.3	7.5	8.6	9.3	5.1	8.2
Nagpur	7.9	8.9	8.7	9.3	9.0	5.1	2.6	2.5	5.4	7.5	8.1	8.1	7.3	8.4	9.0	3.9	7.9
Average Vidarbha	**8.1**	**8.9**	**8.9**	**9.4**	**9.2**	**5.9**	**3.3**	**3.1**	**5.8**	**7.8**	**8.2**	**8.2**	**7.4**	**8.5**	**9.2**	**4.5**	**8.1**
Average State	**8.6**	**9.3**	**9.2**	**9.5**	**9.3**	**5.5**	**3.0**	**3.2**	**5.3**	**7.4**	**8.2**	**8.3**	**7.2**	**8.9**	**9.4**	**4.2**	**8.0**

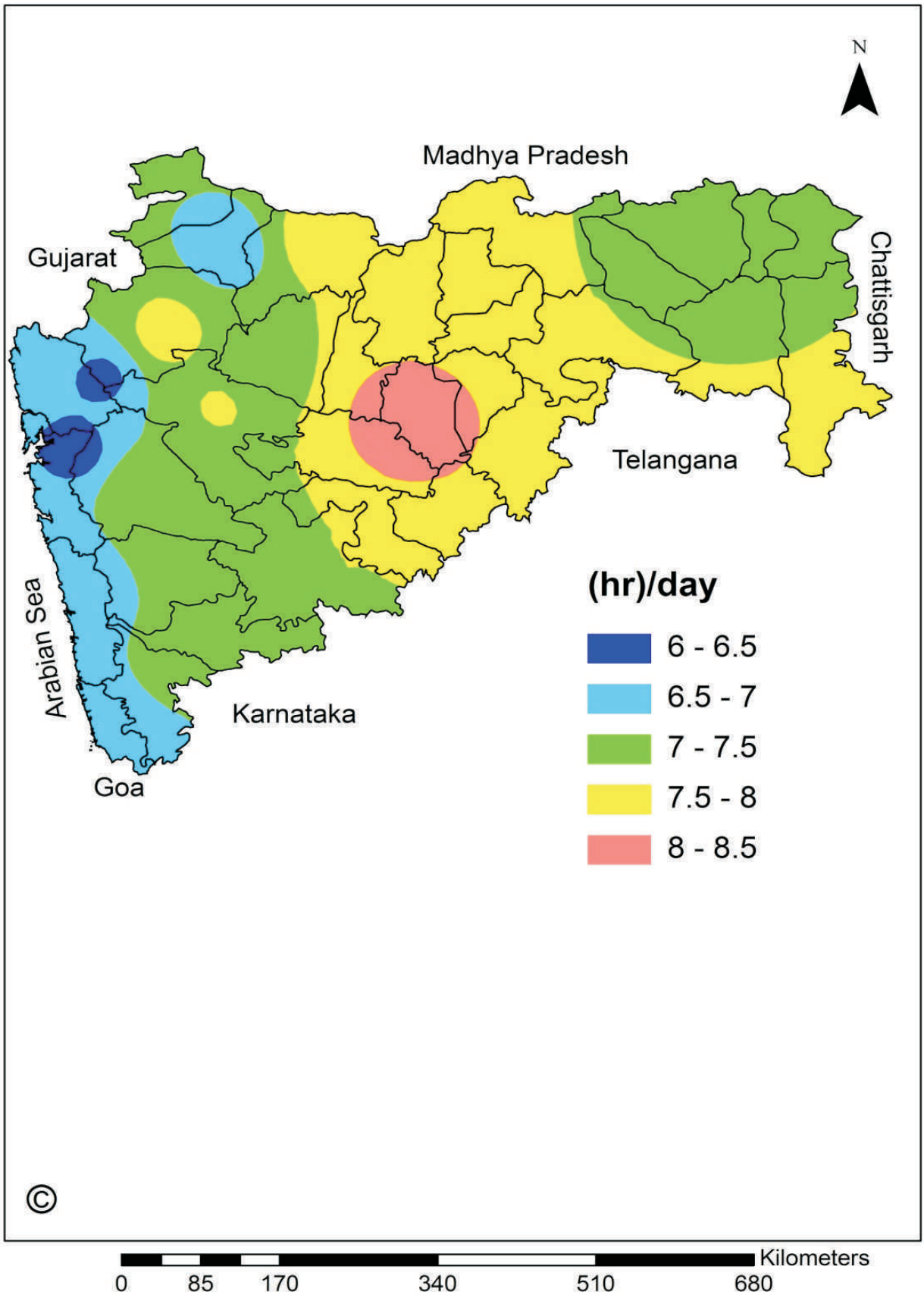

Fig. 118 : Annual mean sunshine hours over Maharashtra

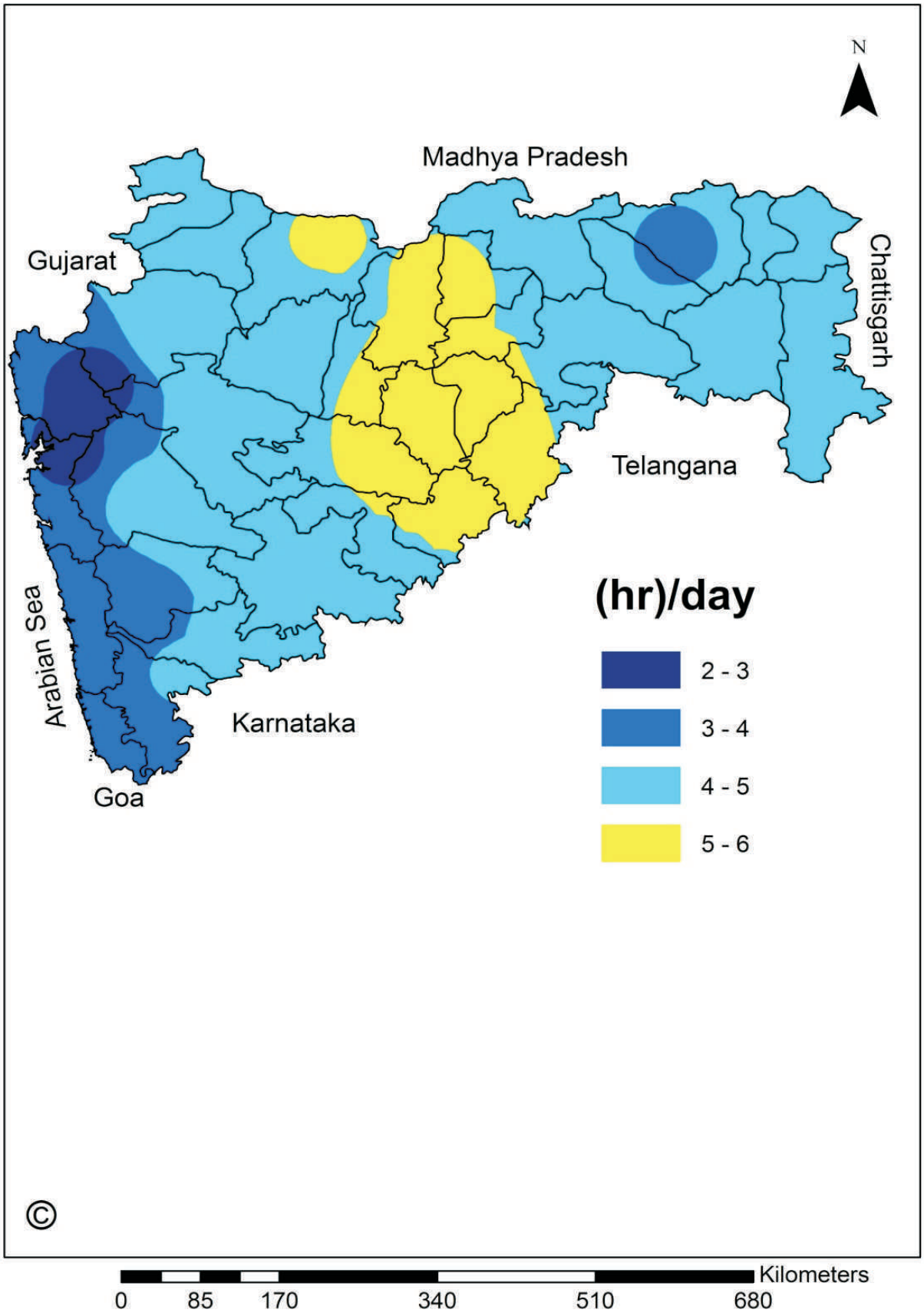

Fig. 119: Southwest monsoon season mean sunshine hours over Maharashtra

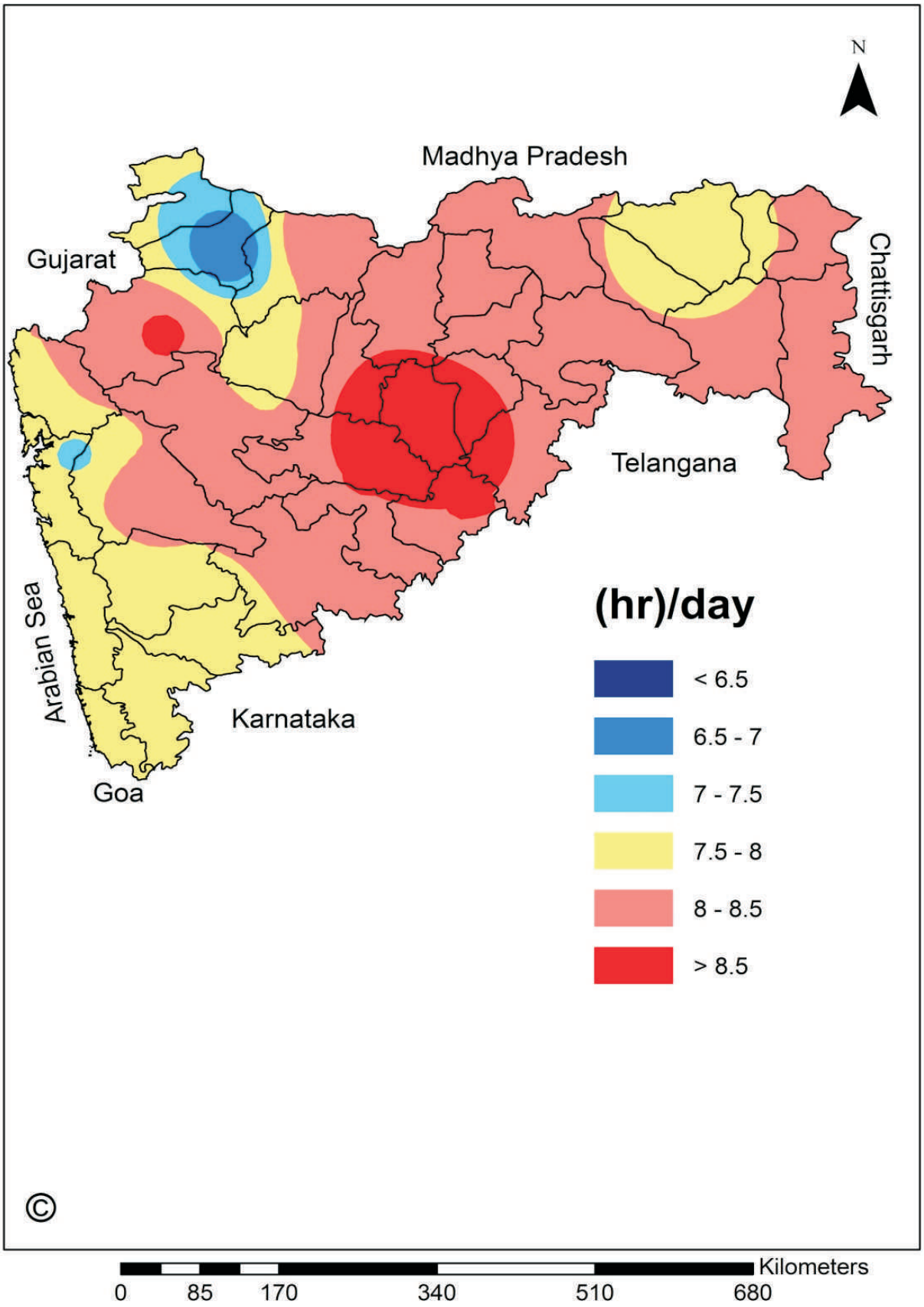

Fig. 120: Post monsoon season mean sunshine hours over Maharashtra

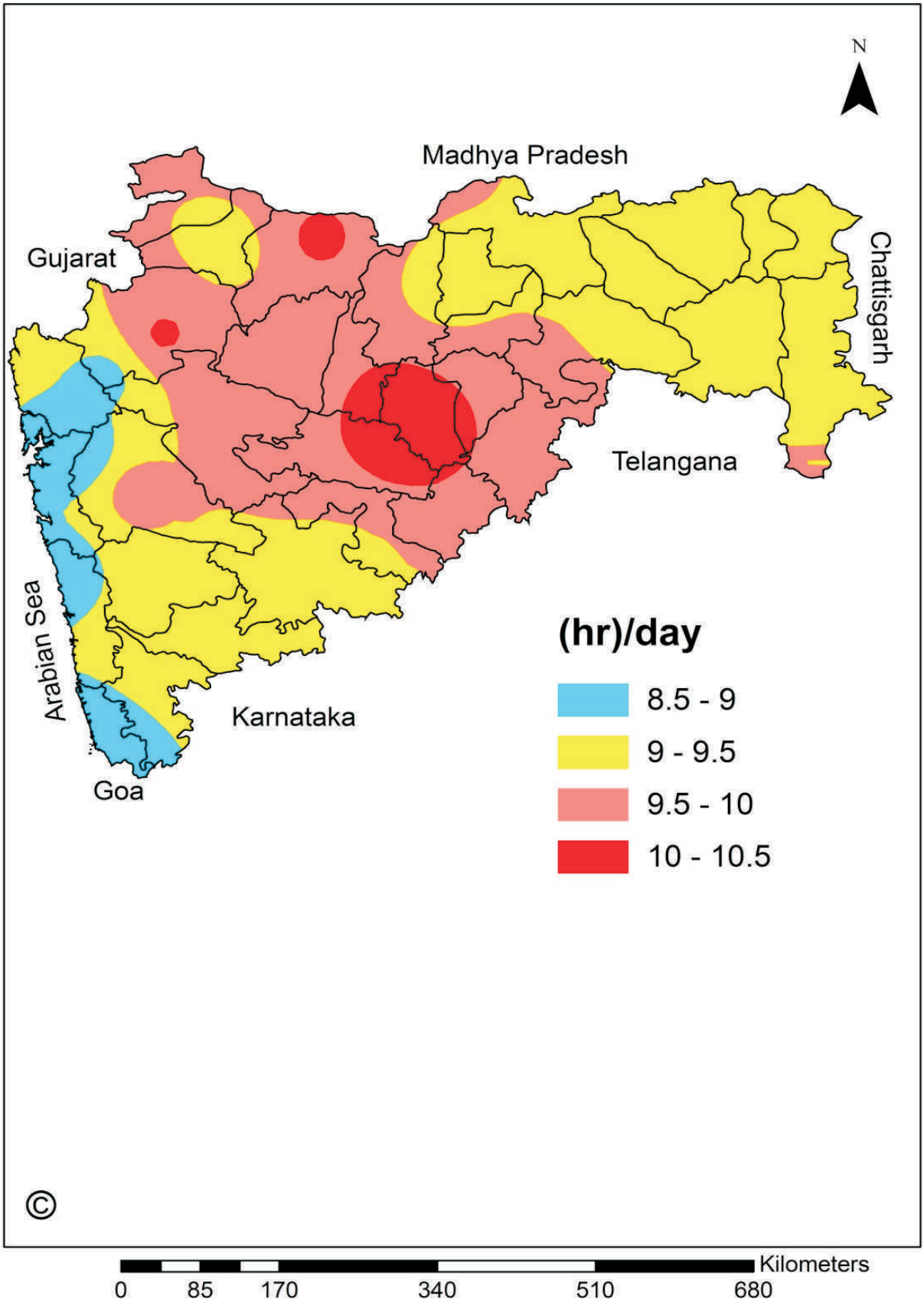

Fig. 121: Summer season mean sunshine hours over Maharashtra

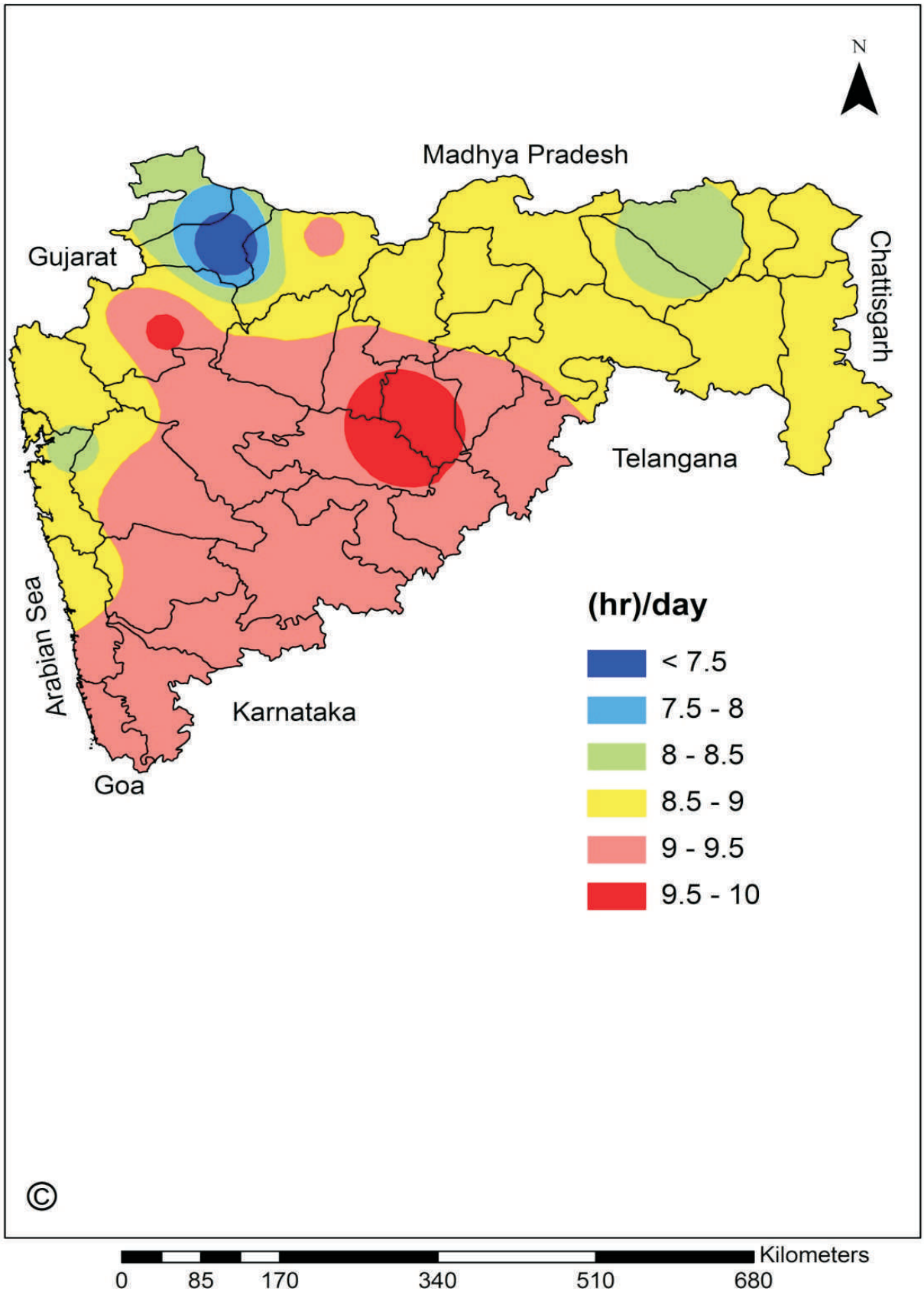

Fig. 122: Winter season mean sunshine hours over Maharashtra

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 2191 mm. Evaporation in the *Marathwada* region is the highest (2451 mm) and is lowest over *Konkan* region (1456 mm). *Vidarbha* and *Madhya Maharashtra* region records total annual evaporation of 2322 mm and 2282 mm, respectively (Fig. 123). Amongst the locations Akola ranked first with an annual evaporation value of 2739 mm followed by Solapur (2731 mm). Least evaporation is recorded in Kudal (1427 mm) followed by Dapoli (1485 mm).

On monthly basis, May is the month of maximum evaporation; the total evaporation for May is 332 mm for the entire state followed by April (289 mm). Region wise *Vidarbha* records highest evaporation (407 mm) followed by *Marathwada* (395 mm), *Madhya Maharashtra* (333 mm) and the least in *Konkan* (180 mm). During May amount of highest evaporation is recorded in Akola (503 mm) followed by Jalgaon (411 mm). The least evaporation during this month has been observed in Kudal (171 mm) followed by Dapoli (189 mm) (Table 30).

The seasonal total evaporation during SWM, for the state as a whole is 603 mm with *Marathwada* registering 702 mm seasonal evaporation followed by *Vidarbha* (663 mm), *Madhya Maharashtra* (621 mm) and *Konkan* (381 mm) (Fig. 124). Amongst the locations, Solapur experiences high evaporative conditions during SWM season with a total E_0 value of 800 mm followed by Akola (781 mm) and Rahuri (734 mm).Least evaporation occurs during this season in Dapoli (345 mm), followed by Kudal (417 mm) and Kolhapur (424 mm). During post monsoon season the total seasonal evaporation for the entire state is 422 mm with *Madhya Maharashtra* registering a peak value of 451 mm and *Konkan* region with the least value of 329 mm (Fig. 125). Location wise, Dhule tops the list with 598 mm of seasonal E_0 followed by Solapur (514 mm). During this season Kudal experiences lowest evaporative demand with a total seasonal evaporation value of 300 mm followed by Nagpur (353 mm).

Summer season records highest evaporation (860 mm) over the state. *Vidarbha* region on an average experiences highest total evaporation of 983 mm and *Konkan* region records lowest total evaporation of 509 mm. During the summer season Akola district location experiences the highest evaporative demand with a seasonal total of 1190 mm followed by Solapur (1024 mm). Kudal (484 mm) and Dapoli (533 mm) experience lower evaporation during summer (Fig. 126). Winter is the season during which least evaporation occurs (305 mm for state) and *Madhya Maharashtra* region tops with a seasonal total value of 325 mm. Dhule location tops in winter season evaporation with a value of 414 mm closely followed by Solapur (394 mm). Least evaporation during winter season occurs over Kudal (226 mm) and Dapoli (249 mm) in *Konkan* region (Fig. 127).

Table. 30 : Monthly open-pan evaporation (mm) for some districts of Maharashtra

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Winter	Summer	SWM	PM
Dapoli	118	131	165	179	189	101	71	80	94	120	124	114	1485	249	533	345	358
Kudal	107	119	150	163	171	113	102	102	99	102	100	98	1427	226	484	417	300
Average Konkan	**112**	**125**	**158**	**171**	**180**	**107**	**87**	**91**	**97**	**111**	**112**	**106**	**1456**	**237**	**509**	**381**	**329**
Dhule	200	214	271	311	356	234	127	112	156	205	199	194	2579	414	938	629	598
Jalgaon	135	158	234	316	411	274	140	110	133	178	147	147	2383	294	961	657	472
Kolhapur	137	166	224	247	248	135	92	88	109	124	121	129	1822	303	720	424	375
Igatpuri	158	187	245	263	273	183	108	107	116	135	160	166	2101	345	781	514	461
Niphad	135	164	261	329	379	242	160	127	142	182	160	133	2414	299	968	672	475
Padegaon	129	162	246	286	295	186	141	132	144	145	124	117	2105	291	826	603	385
Pune	127	159	236	282	304	193	127	117	120	136	125	118	2042	285	821	556	379
Rahuri	137	165	248	310	362	242	186	160	146	149	130	122	2358	302	920	734	402
Solapur	180	214	306	346	372	255	204	175	166	176	169	168	2731	394	1024	800	514
Average Madhya Maharashtra	**149**	**177**	**252**	**299**	**333**	**216**	**143**	**125**	**137**	**159**	**148**	**144**	**2282**	**325**	**884**	**621**	**451**
Parbhani	144	175	258	326	395	249	164	139	150	167	149	134	2451	320	980	702	450
Average Marathwada	**144**	**175**	**258**	**326**	**395**	**249**	**164**	**139**	**150**	**167**	**149**	**134**	**2451**	**320**	**980**	**702**	**450**
Akola	147	184	294	393	503	326	175	135	145	163	144	131	2739	330	1190	781	438
Sindewahi	118	152	226	291	349	236	117	103	115	129	124	125	2085	270	866	571	378
Nagpur	114	142	227	299	369	247	141	120	130	130	114	108	2141	256	894	638	353
Average Vidarbha	**126**	**159**	**249**	**327**	**407**	**270**	**145**	**119**	**130**	**141**	**127**	**121**	**2322**	**286**	**983**	**663**	**390**
Average State	**139**	**166**	**239**	**289**	**332**	**214**	**137**	**120**	**131**	**150**	**139**	**134**	**2191**	**305**	**860**	**603**	**422**

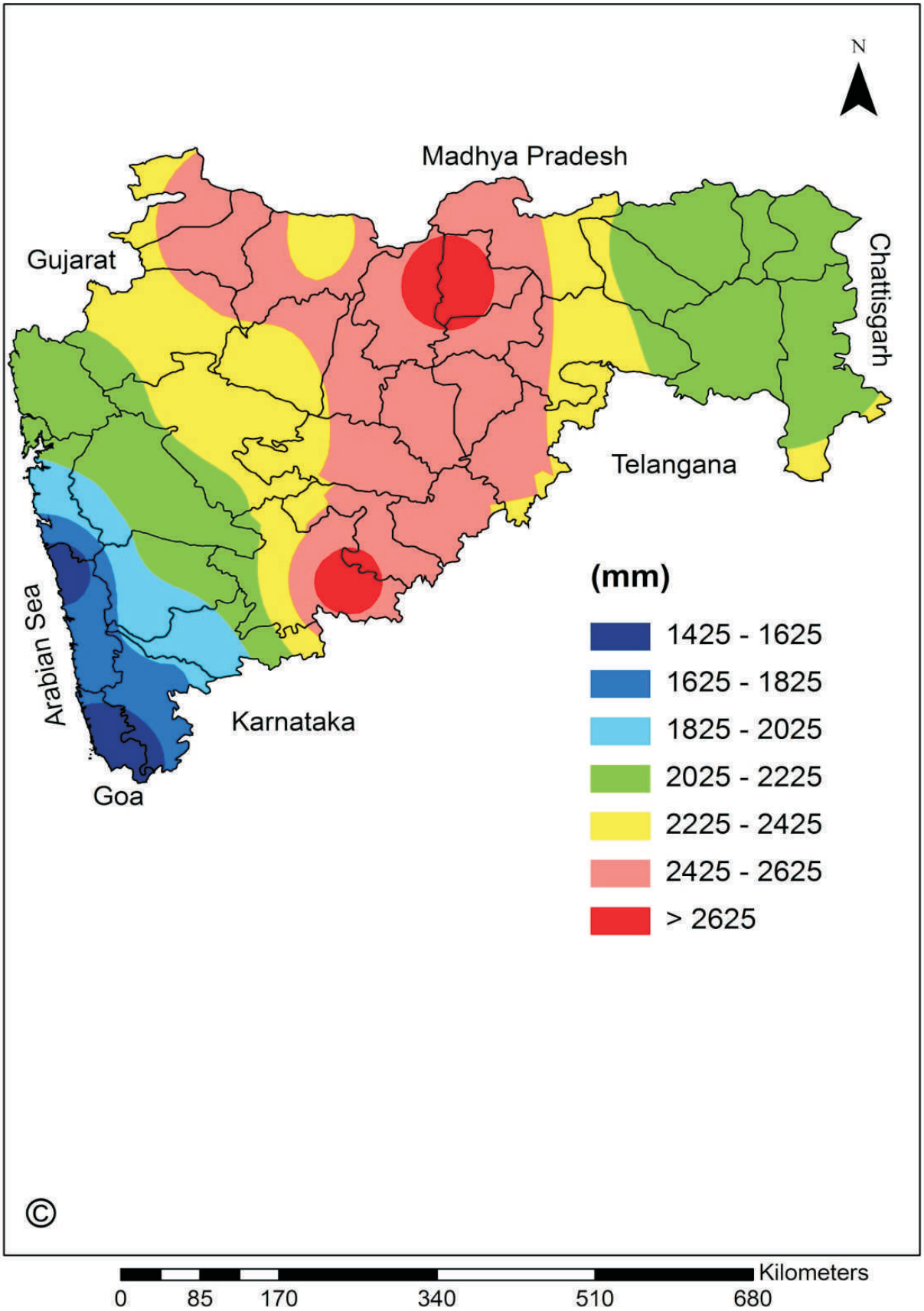

Fig. 123: Annual mean open-pan evaporation over Maharashtra

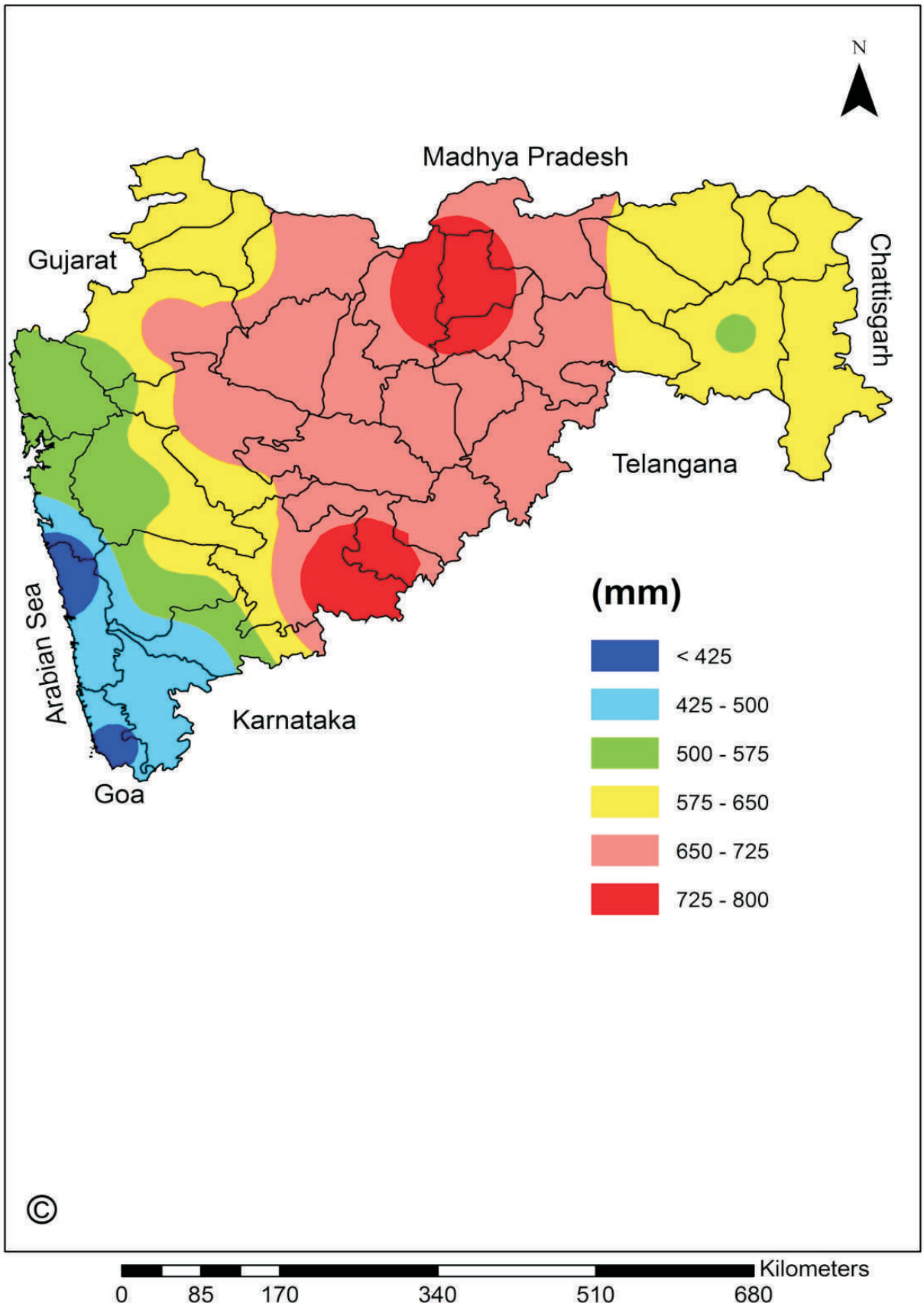

Fig. 124 : Southwest monsoon season mean open-pan evaporation over Maharashtra

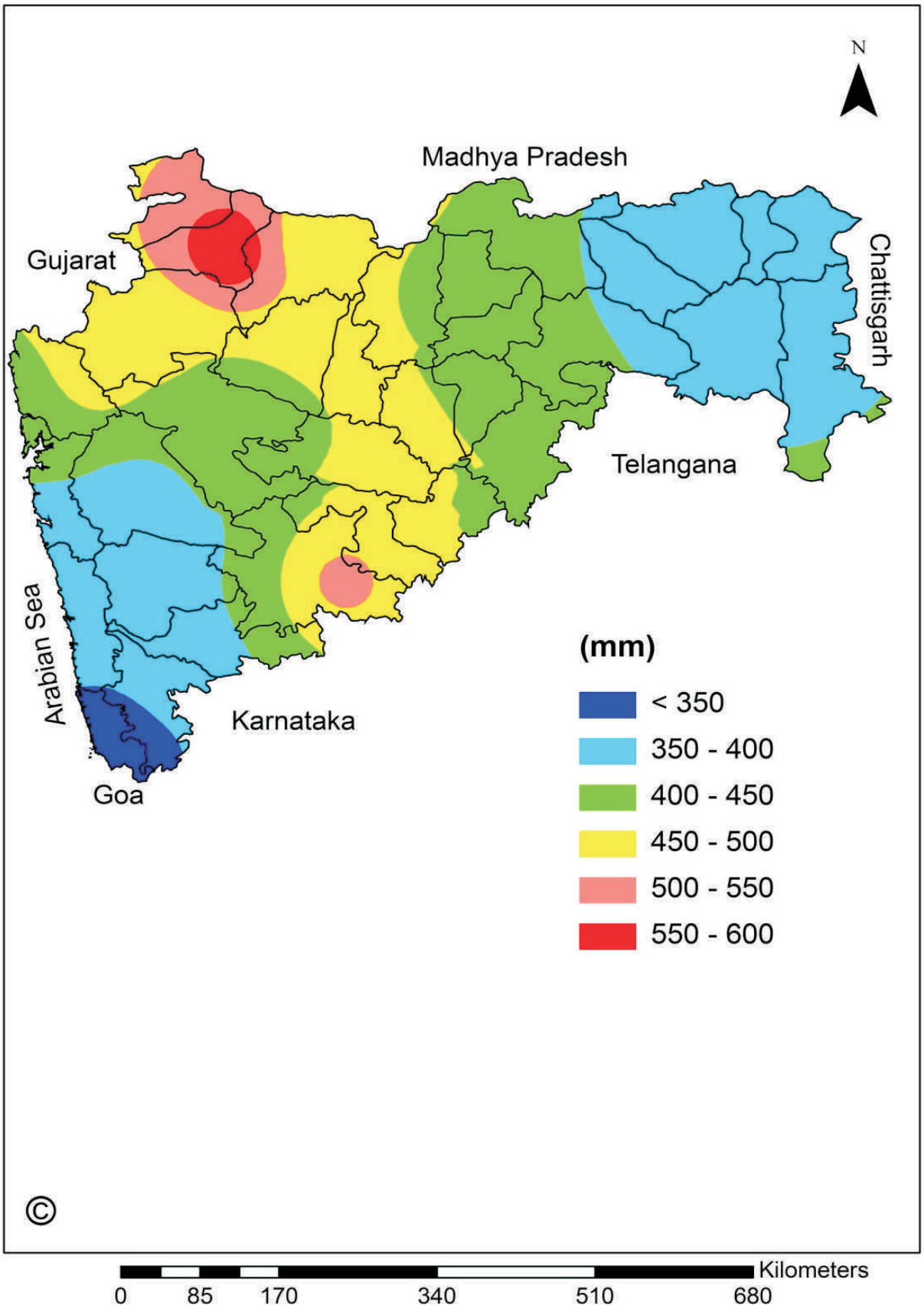

Fig. 125 : Post monsoon season mean open-pan evaporation over Maharashtra

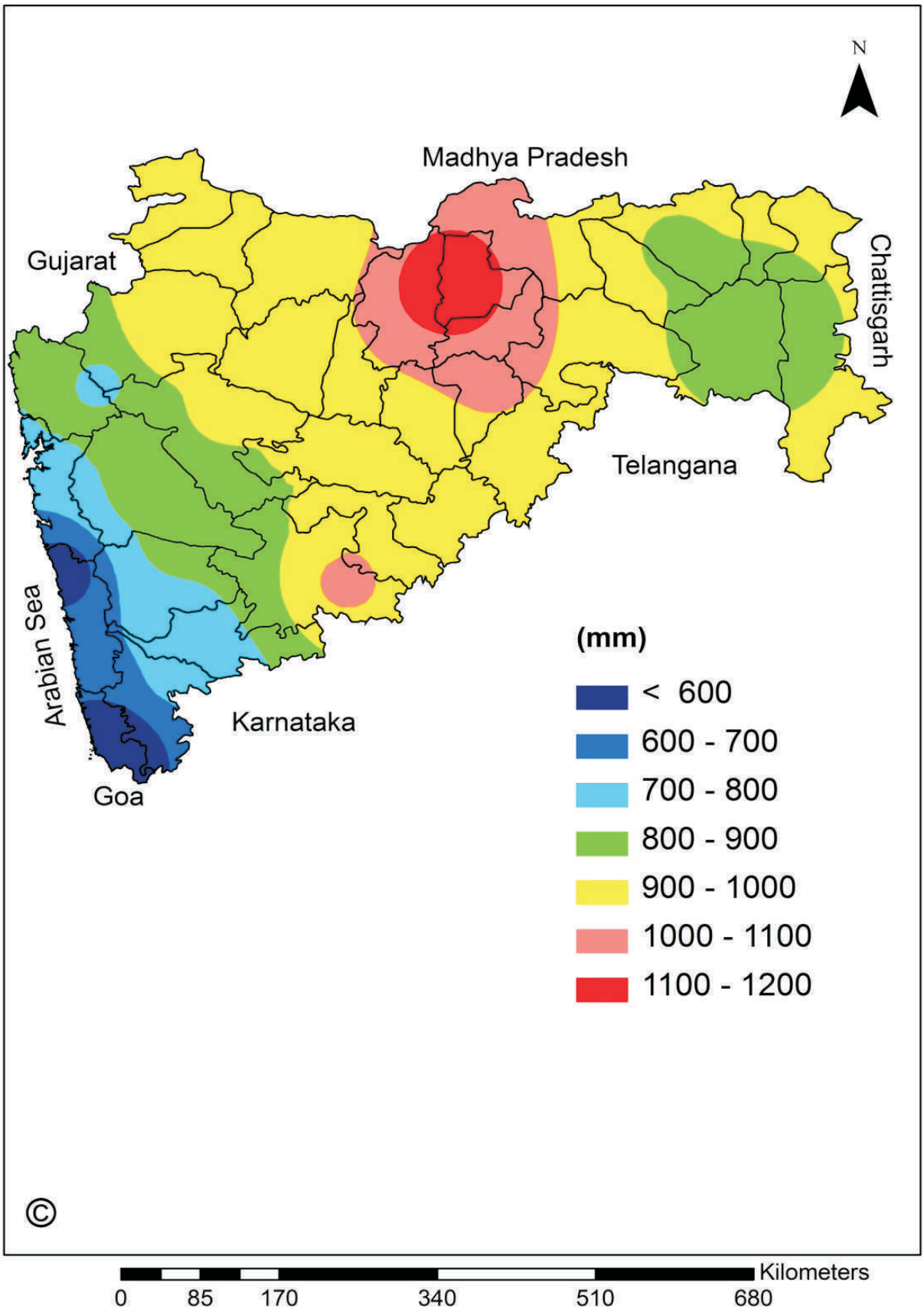

Fig. 126 : Summer season mean open-pan evaporation over Maharashtra

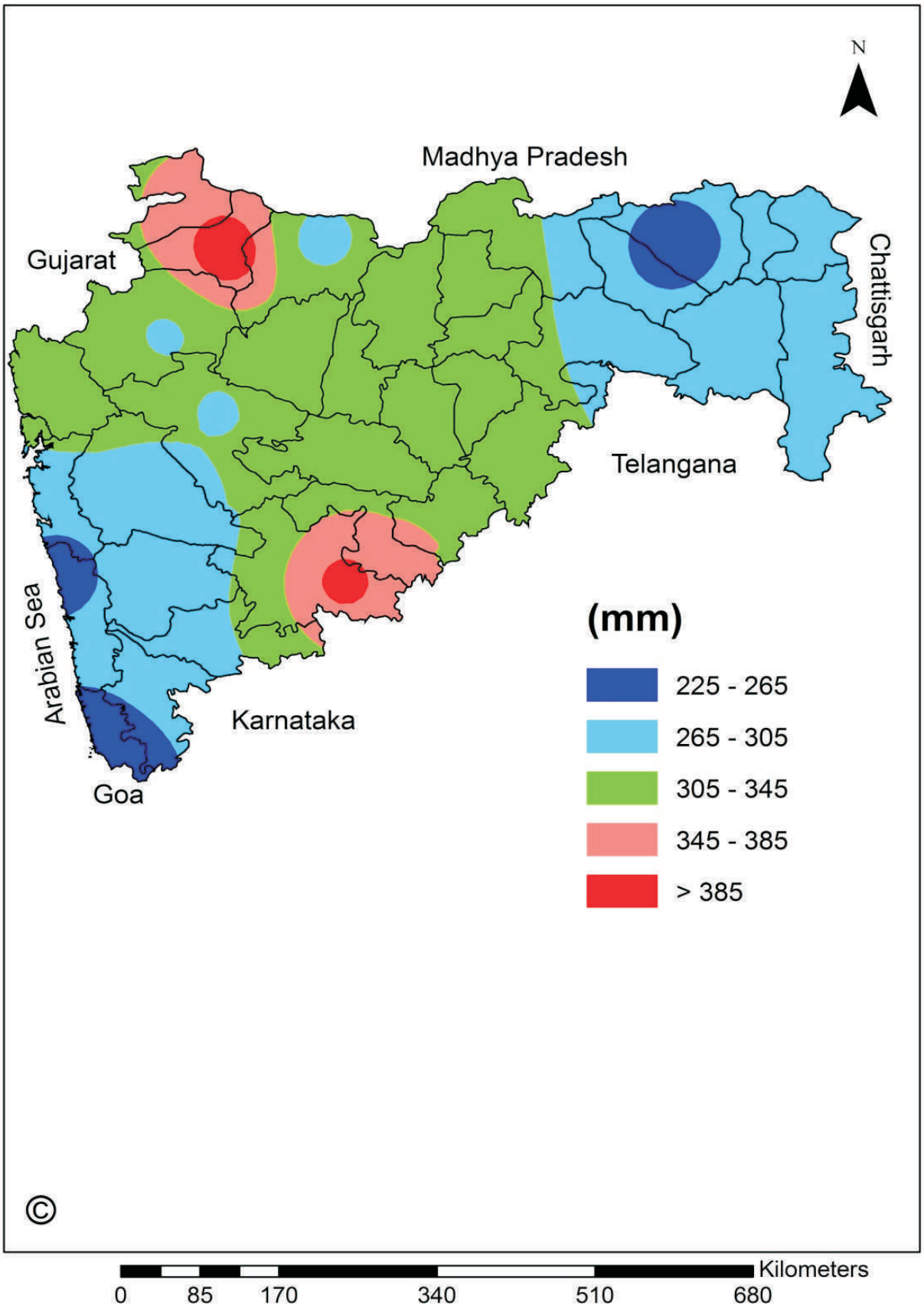

Fig. 127 : Winter season mean open-pan evaporation over Maharashtra

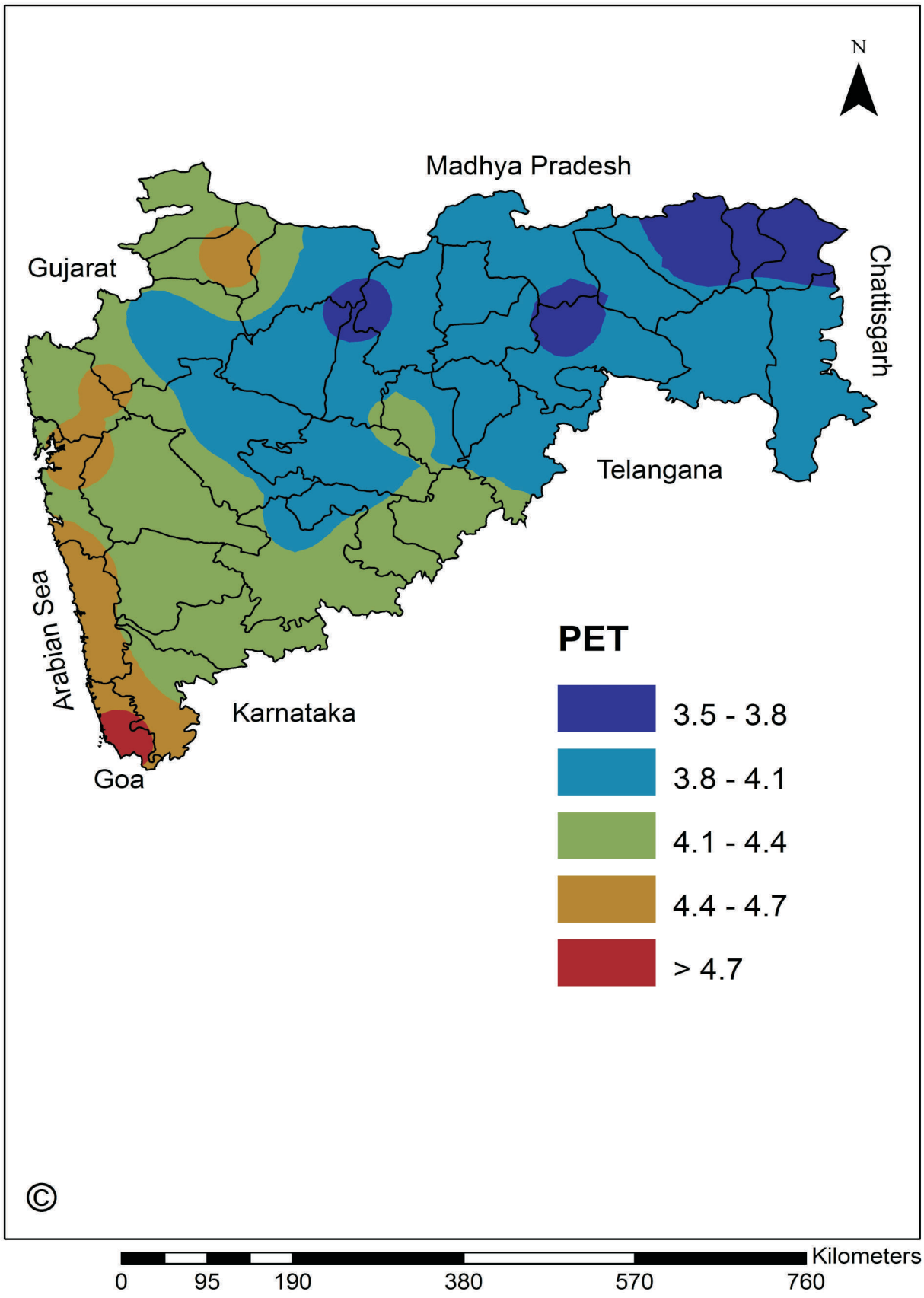

Fig. A1 : Potential evapotraspiration (mm/day) for the month of January over Maharashtra

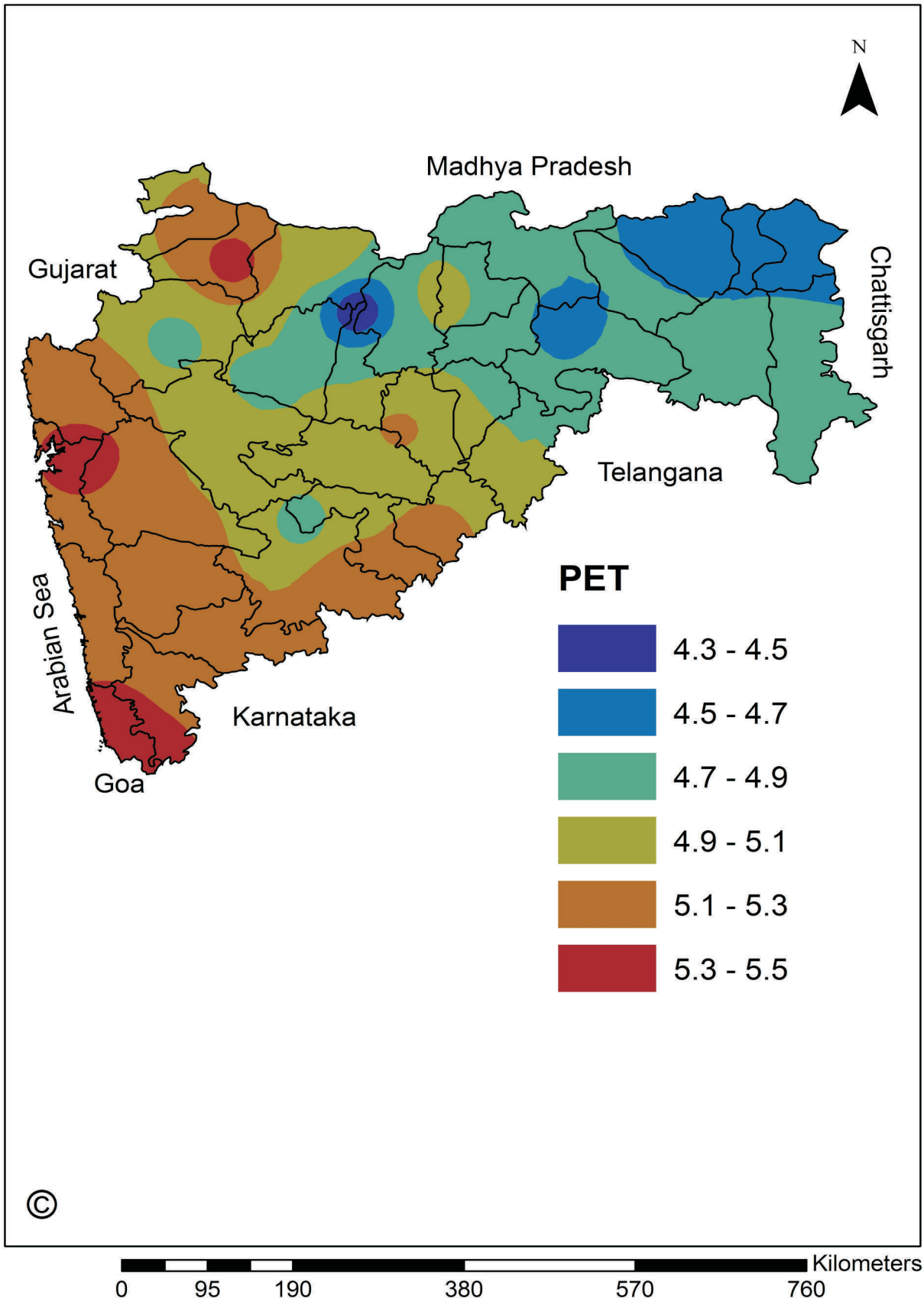

Fig. A2 : Potential evapotraspiration (mm/day) for the month of Feburary over Maharashtra

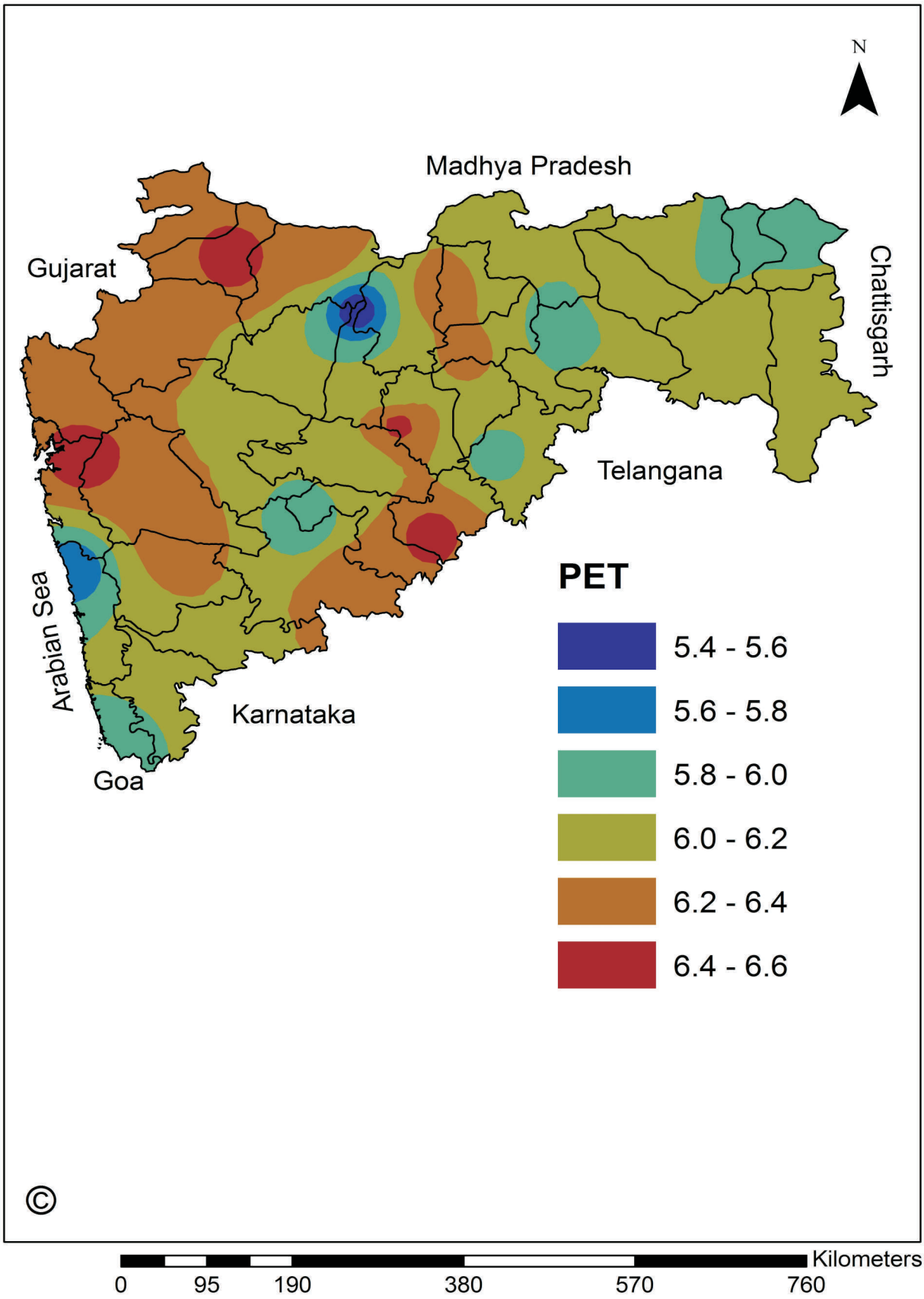

Fig. A3 : Potential evapotraspiration (mm/day) for the month of March over Maharashtra

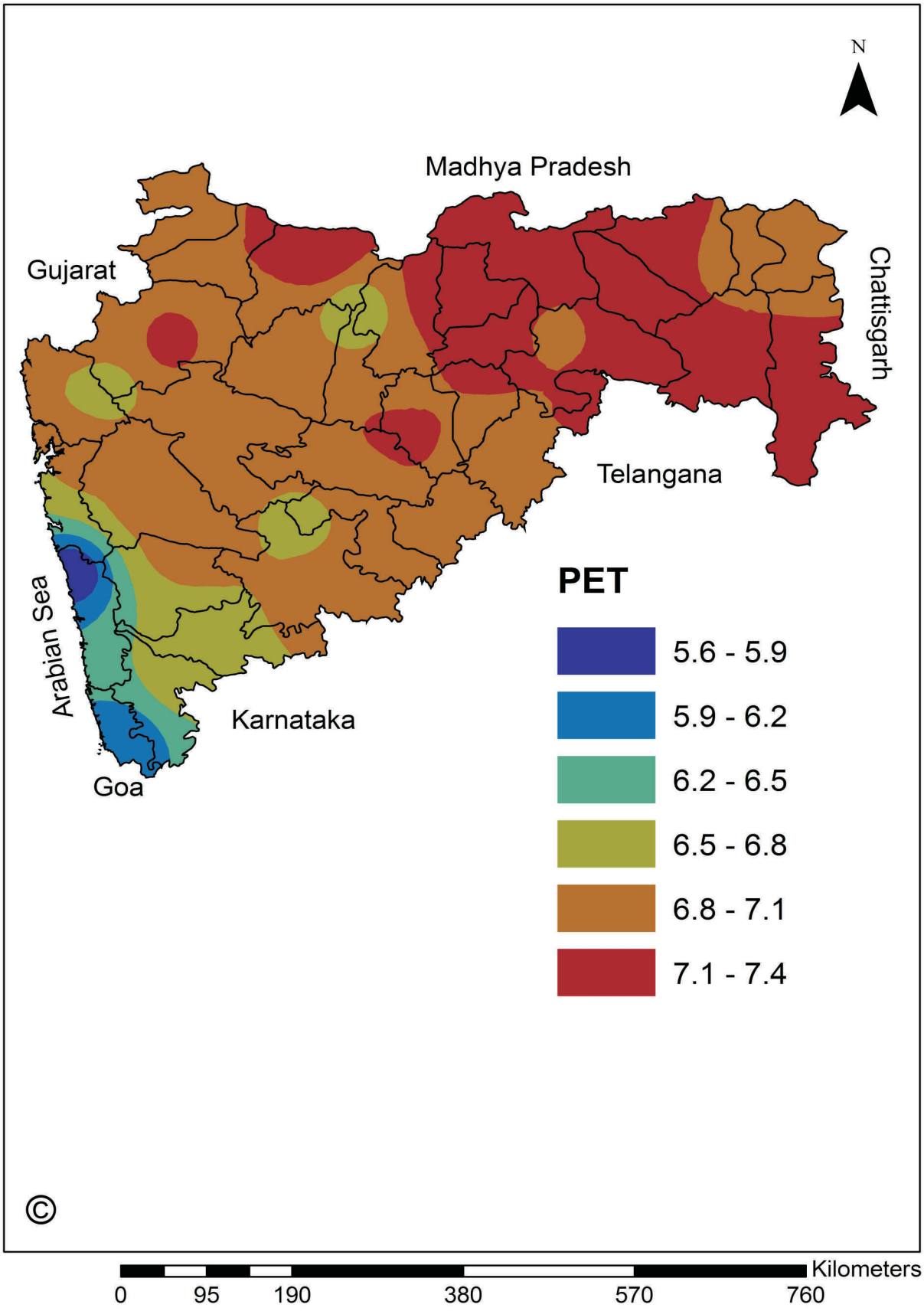

Fig. A4: Potential evapotraspiration (mm/day) for the month of April over Maharashtra

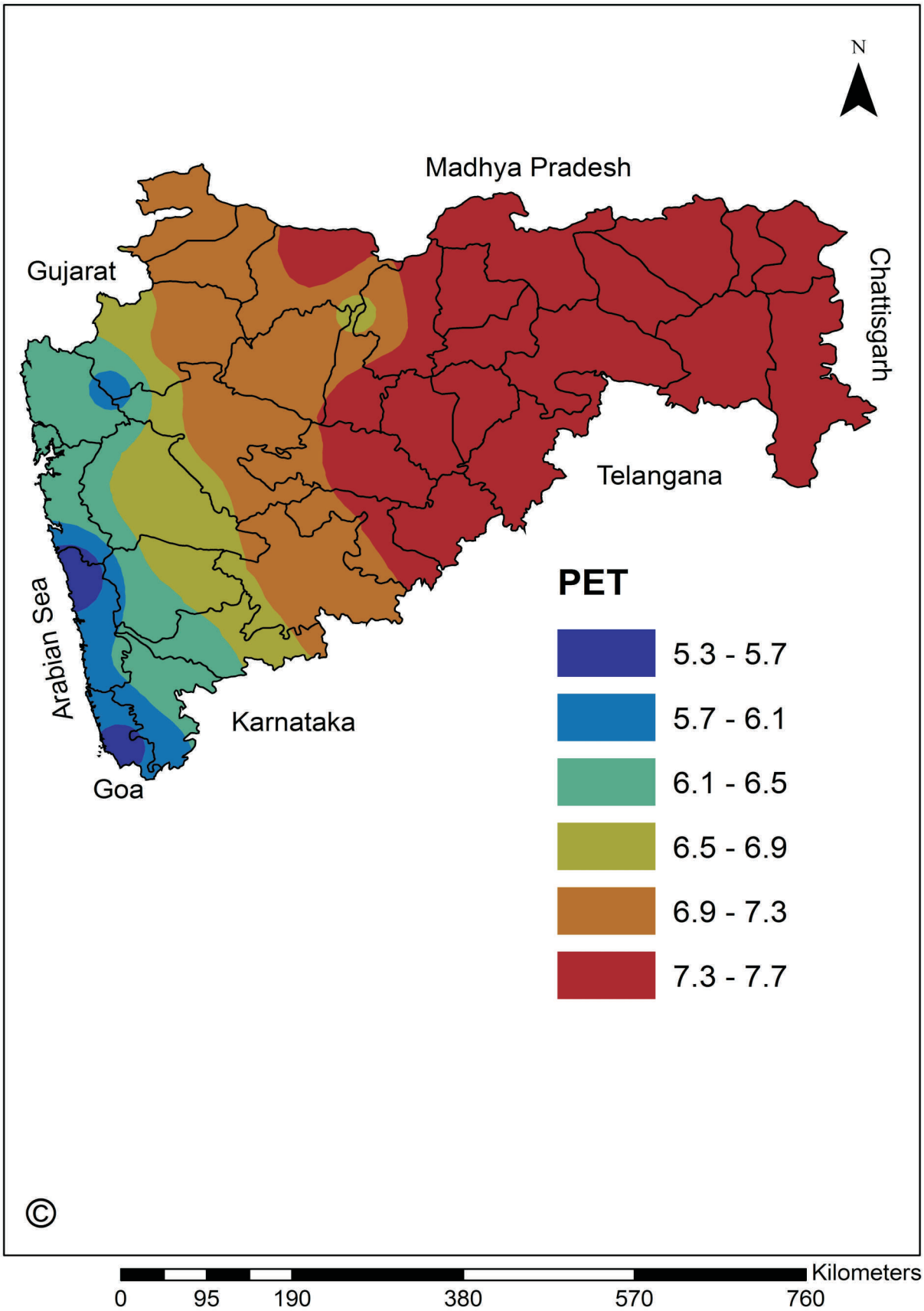

Fig. A5 : Potential evapotraspiration (mm/day) for the month of May over Maharashtra

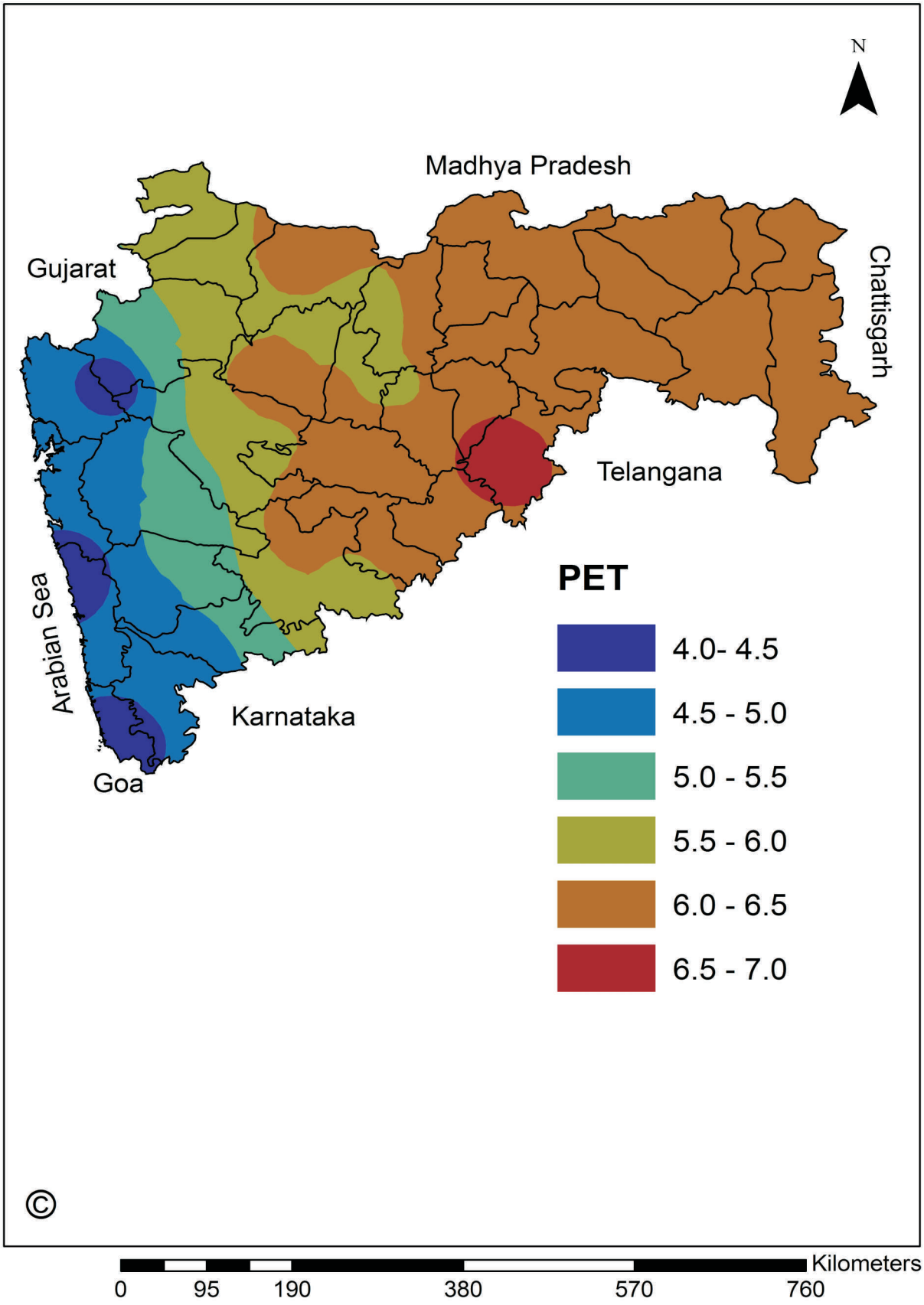

Fig. A6 : Potential evapotraspiration (mm/day) for the month of June over Maharashtra

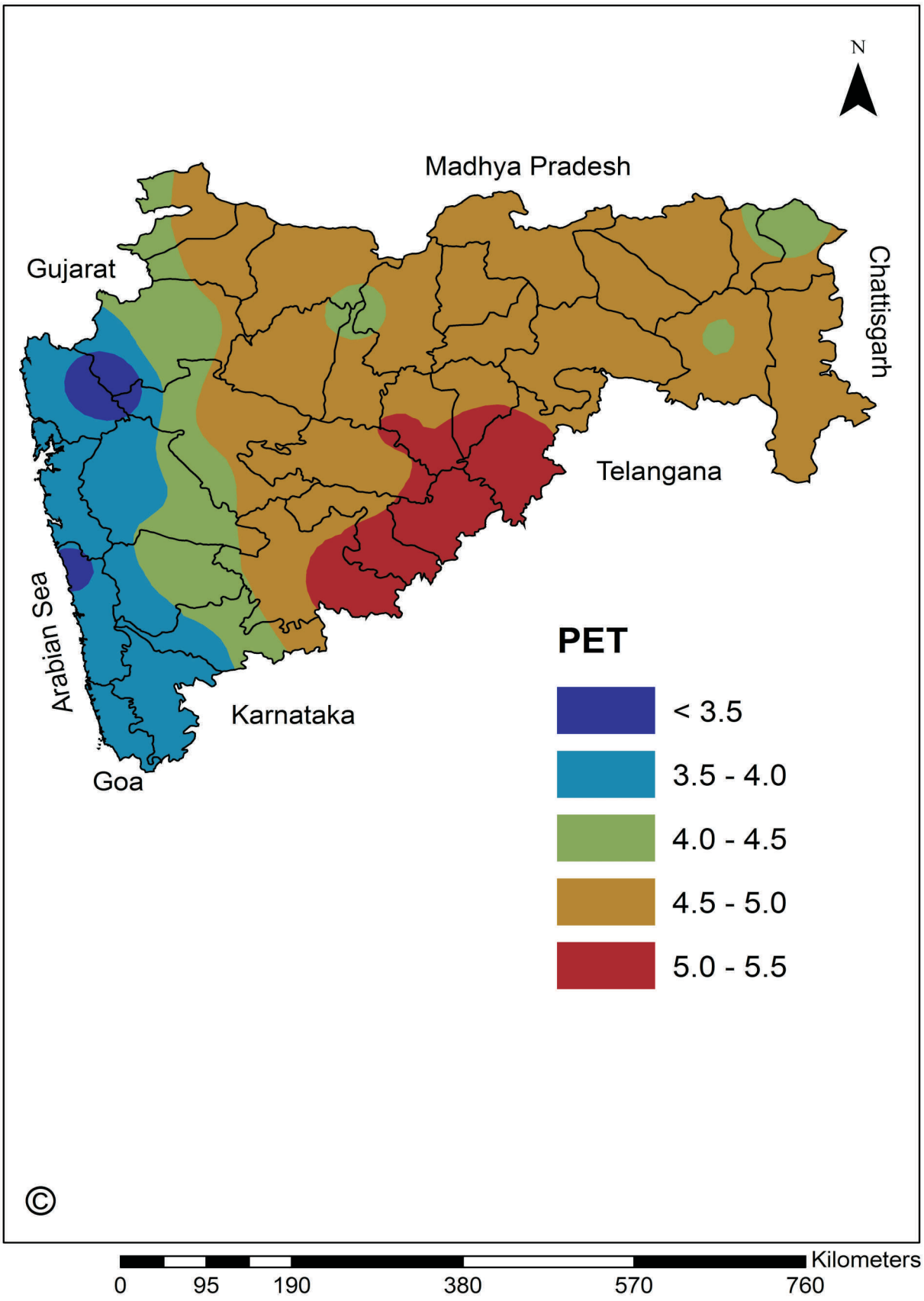

Fig. A7 : Potential evapotraspiration (mm/day) for the month of July over Maharashtra

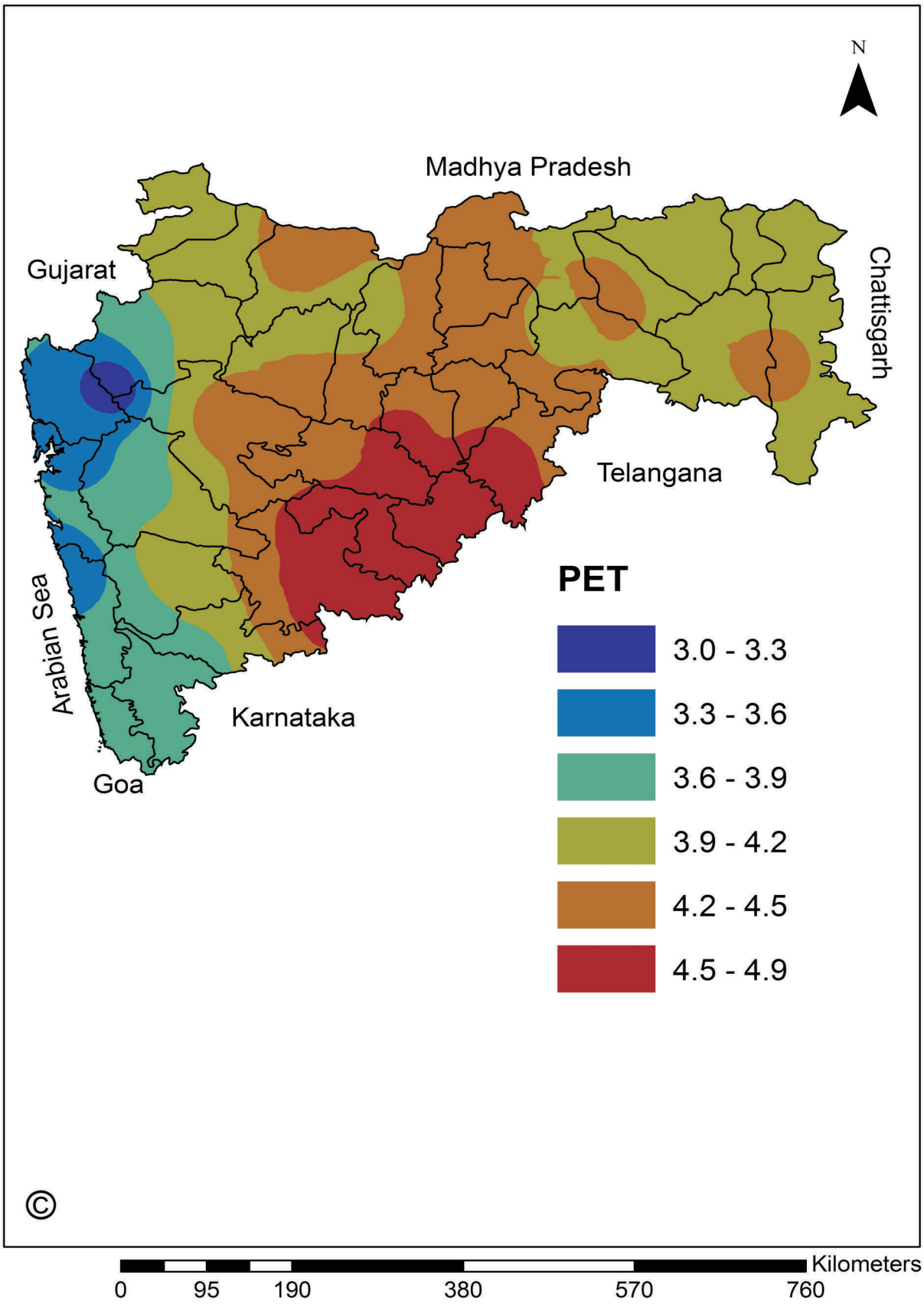

Fig. A8 : Potential evapotraspiration (mm/day) for the month of August over Maharashtra

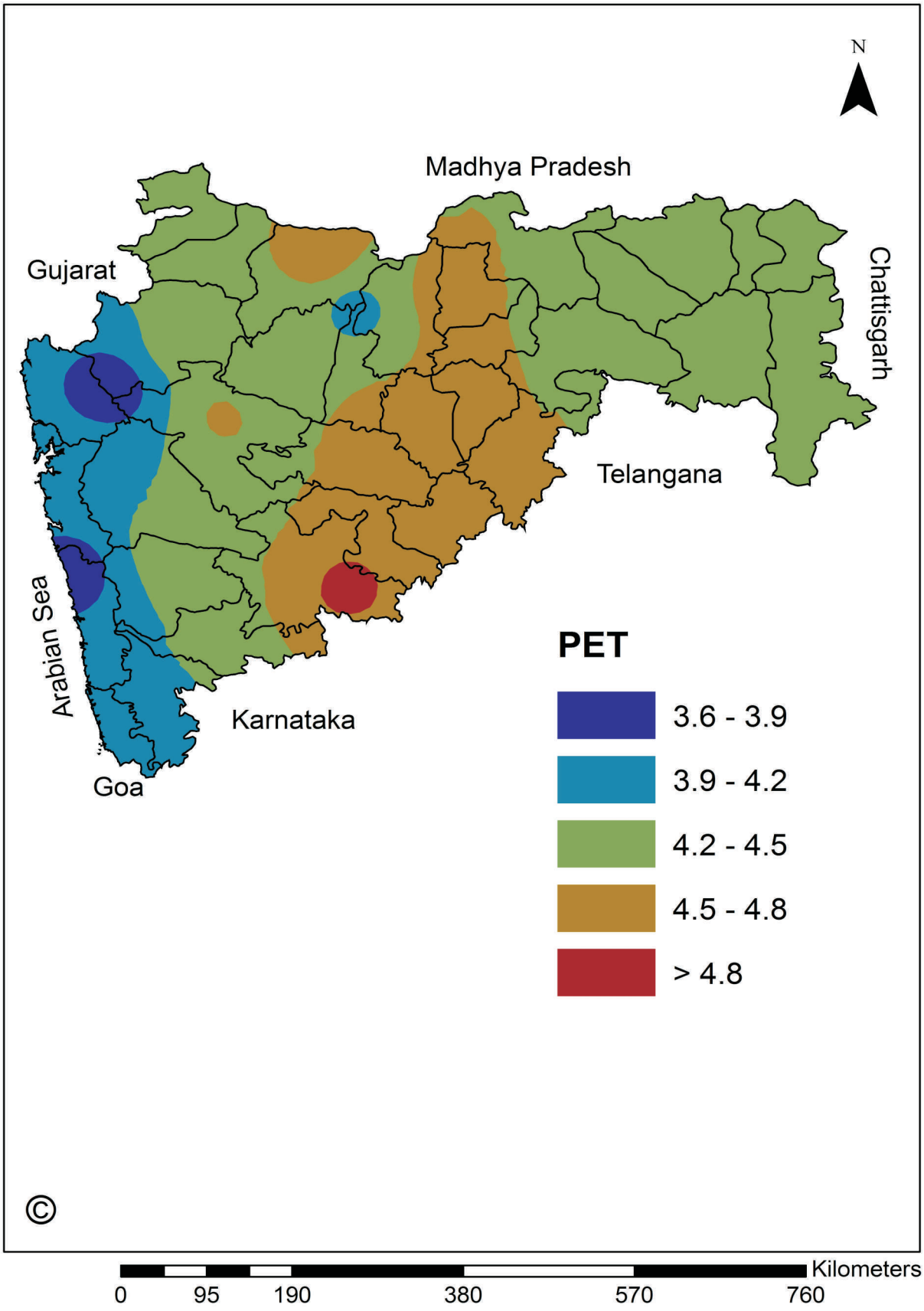

Fig. A9 : Potential evapotraspiration (mm/day) for the month of September over Maharashtra

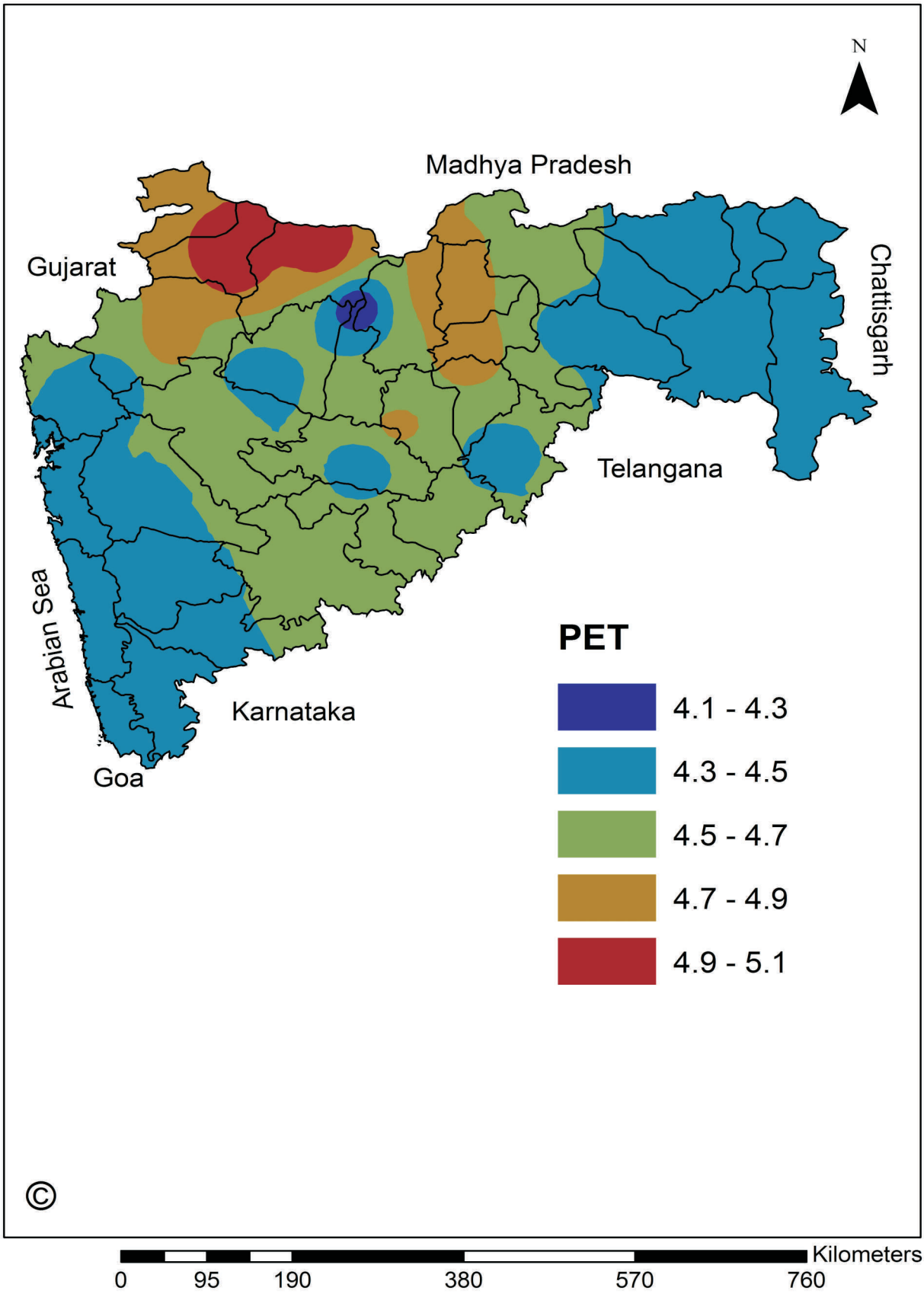

Fig. A10 : Potential evapotraspiration (mm/day) for the month of October over Maharashtra

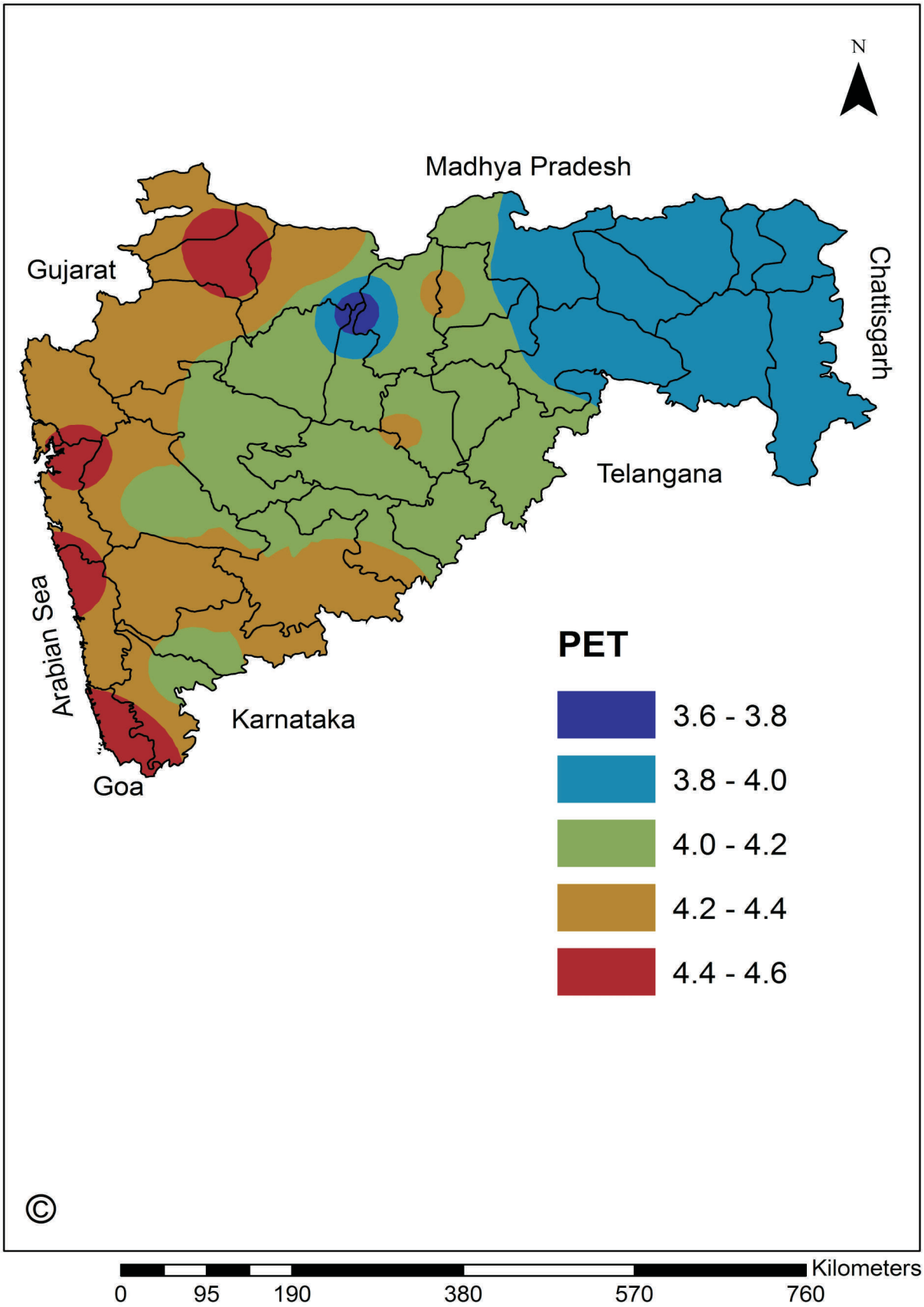

Fig. A11 : Potential evapotraspiration (mm/day) for the month of November over Maharashtra

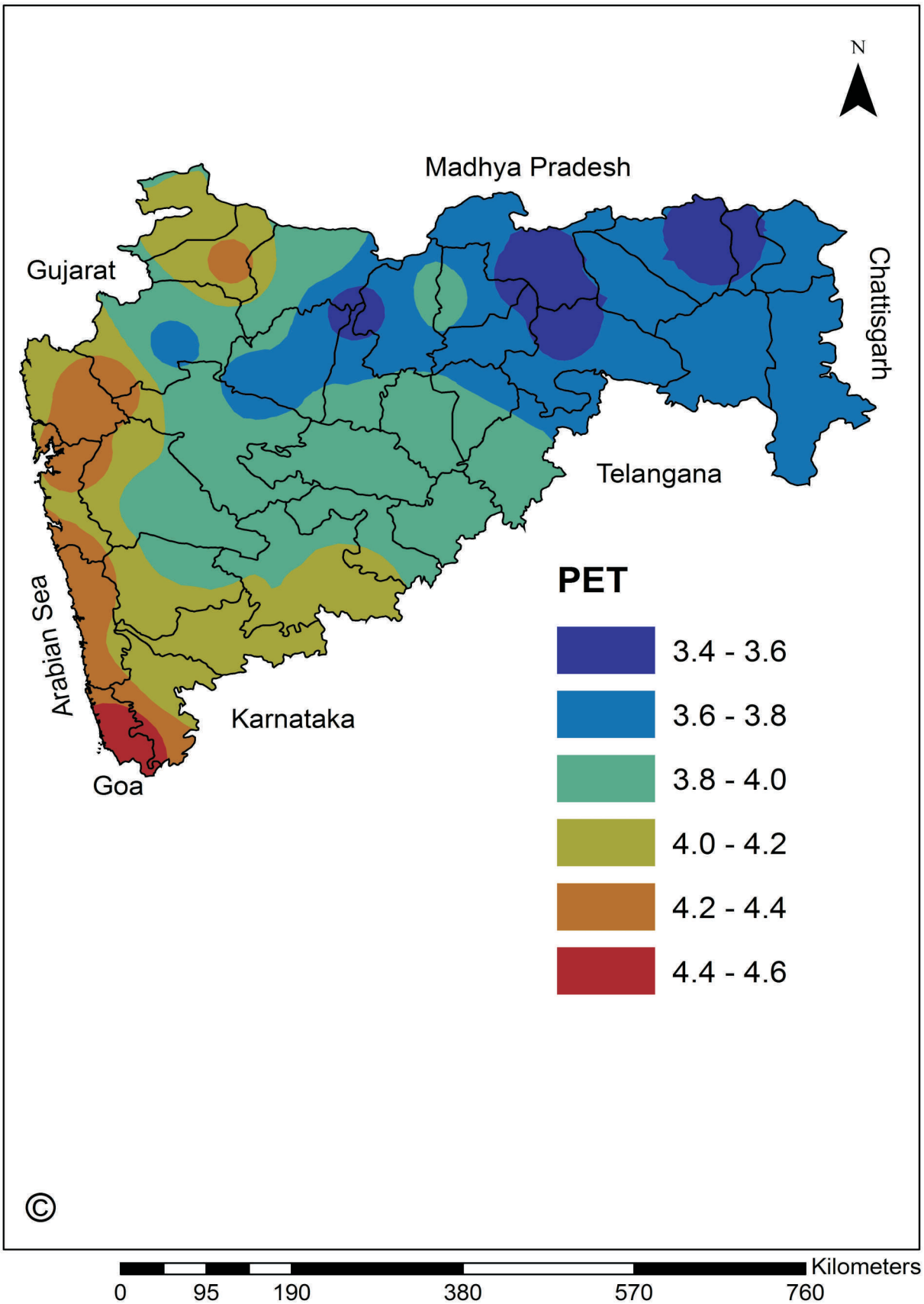

Fig. A12 : Potential evapotraspiration (mm/day) for the month of December over Maharashtra





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