CLIMATE RISK AND VULNERABILITY ASSESSMENT

I. INTRODUCTION

1. Transport has been an essential element in the development of Asia and the Pacific, and has played a critical role in the region's rapid economic growth (ADB, 2017). It has helped move people and goods, ensuring that labor, raw materials, products, and ideas can move around easily and contribute to the social, economic, and environmental improvement of the region.[1] Over the last few decades, transport infrastructure in India has improved to respond to higher transport demand. More recently, concerns on road's quality, maintenance, and safety as well as environmental impacts of road transport, have been considered in road infrastructure development. According to the Lesson from ADB Transport Projects (2017), Asia's developing countries are increasing efforts to address such concerns, while also incorporating climate change resiliency in road development planning and design.

2. The Asia and Pacific region is vulnerable to temperature extremes, and flooding by heavy rainfall, sea level rise, and tropical cyclones (ADB, 2017). Risks from climate change are further amplified by the pace of population growth and rapid development of urban areas. Both trends are concentrating people and assets in places that are potentially exposed to climate threats. Climate change also has implications for food, water, and energy security; migration; and the stability of trade networks in the region.

3. The Maharashtra Rural Road Development Association (MRRDA) has adopted climate resilient road designs to address climate risks for the current Rural Connectivity Improvement Project (RCIP). Similar approach is done for the RCIP's Additional Financing by designing the rural roads and bridges to be adaptive to future climate events. Climate risk and vulnerability assessment is carried out for the Additional Financing during project preparation. The assessment identified the climate risks and adaptation measures integrated into the infrastructure design.

Objectives of the CRVA

4. To improve the adaptive capacity of the MRRDA, this study assesses the climate change vulnerability of the project roads and bridges. The objectives of the CRVA are:

(i) assess exposure, sensitivity, and adaptive capacity of Maharashtra RCIP Additional Financing to climate risks;
(ii) identify and prioritize region and district climate risks that threatens the resilience of the project rural roads; and
(iii) integrate in the detailed project reports (DPRs) climate-risk responsive road and bridge features

Methodology, scope and limitations

5. The CRVA started with the review of climate change projections and climate risks from various sources. These climate scenarios are expressed in terms of temporal and spatial variations on temperature and rainfall in the state. This is followed by a description of the project's climate change sensitivity that is dictated by the location hazards which potentially exacerbated by the forecasted changes in temperature and rainfall and. Through the information of the project

[1] United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). 2013. Transport Review 2013. www.unescap. org/sites/default/files/transportreview_2013_full_text.pdf

locations and information on the districts' projected climate allowed the initial assessment of the potential impacts of climate change.

6. Field observation followed the climate risk researches by means of transect walks of the project roads and bridges. Transect walk is a participatory approach of gathering baseline, identifying environmental and climate risks, and formulating adaptation options by walking along the entire stretch of the project road. Identified potential climate change impacts from the map overlays and transect walks were addressed in the DPRs that incorporated engineering design and safeguard assessment findings and recommendations.

7. For the Additional Financing, the principal climate risk is attributed to the increase of rainfall, temperature and the sensitivity of the roads and bridges to flooding, cyclones and landslides. Adaptive structural measures in terms of additional or bigger drainage, additional retaining walls, increase in road surface elevation, and construction on new side drains were included in the road design while the capacity building of the MRRDA in terms of planning and construction forms part of the implementation support consultant's terms of reference. List below enumerates the activities undertaken for this study:

(i) review of climate change projection literatures in the region, and the State,
(ii) review of the risks to the rural roads and bridges that can be exacerbated by climate change from different studies,
(iii) assess the sensitivity of rural roads and bridges to projected increase in temperature and rainfall,
(iv) use of online tools that defines the projected climate risks of Maharashtra's districts,
(v) conduct transect walk to all roads and identify with the field engineers and concerned communities' particular sections of the roads that are prone to the identified climate impacts,
(vi) engage the engineers and community to formulate engineering adaptation measures that should be included in the project design, and
(vii) estimate the costs of adaptation measures for each road.

8. The succeeding figure is the framework followed to determine the risks and vulnerability of the rural roads and bridges.

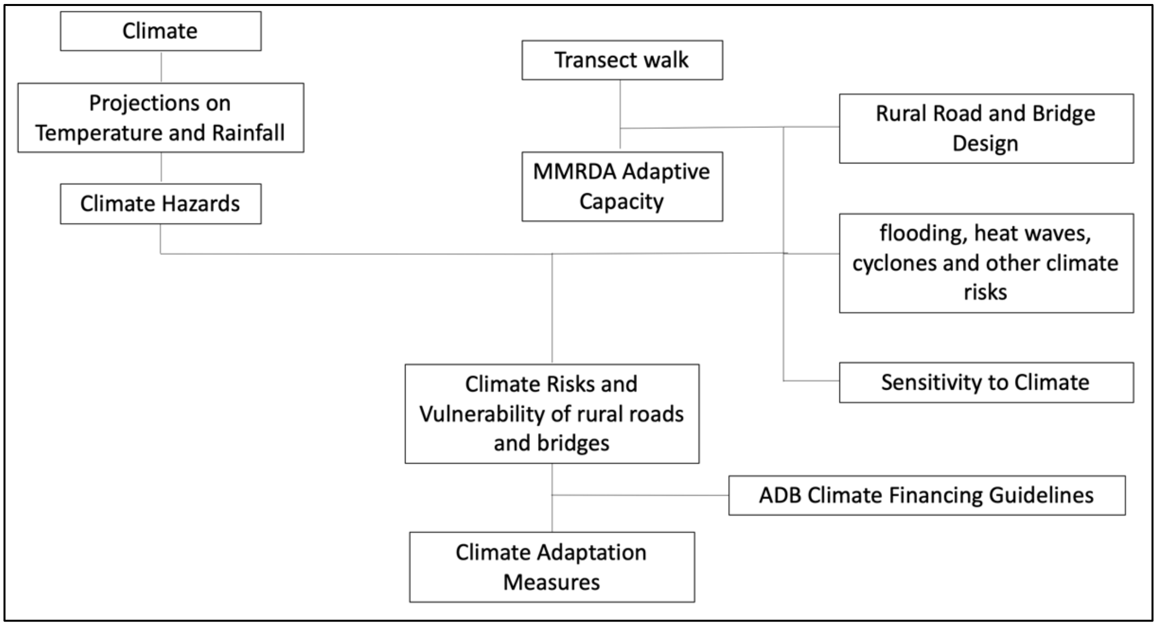


Figure 2. Framework of the CRVA.

II. PROJECT DESCRIPTION

9. To address remaining needs of rural connectivity and in response to the severe August 2019 floods[2], the RCIP—Additional Financing will scale up the road condition and safety improvement works of rural roads and urgently rehabilitate bridges to enhance flood resilience and climate adaptation. The additional scopes are strongly linked to the ongoing RCIP and can be implemented under the same arrangements. These roads and bridges will enhance Maharashtra's agriculture value chain together with the government's priorities under the Mukhya Mantri Gram Sadak Yojana (MMGSY) program[3] and ADB's country partnership strategy[4].

10. Distributed across 34 districts, the project will take a large part of the MMGSY program by (i) improving priority rural roads and bridges into all-weather standards (climate resilient), gender-inclusive, and high safety features[5]; and (ii) development of the MRRDA's capacity on road asset management. The roads and bridges will be covered under contractual maintenance for 5 years after the date of construction.[6] The manuals for the road maintenance, climate-resilient designs and rural road construction will also be developed under the project.

Roads

11. The rural roads under the financing will cover 6 regions in the state, which are (i) Amaravati, (ii) Aurangabad, (iii) Konkan, (iv) Nagpur, (v) Nashik and (vi) Pune. Located on a hilly

---

2 A series of floods that affected over 13 states, due to incessant rains. The states of Karnataka and Maharashtra were the most severely affected by the flooding.

3 Governement of Maharashtra, Rural Development and Panchayat Raj Department. 2019. Mukhya Mantri Gram Sadak Yojana. Mumbai.

4 ADB. 2017. *Country Partnership Strategy:* India, 2018 – 2022 – Accelerating Inclusive Economic Transformation. Manila.

5 Road safety measures include cautionary and information signs, guard posts, and speed breakers.

6 Routine maintenance will be undertaken for 5 years by the same contractors that built the roads. All maintenance will be financed by the government.

upland terrain in the Deccan Traps[7]. There are 1,100 rural roads, which cover 2,965 km under the project. The project works in Aurangabad has the most number of rural roads and largest coverage among all the regions. These rural roads are located at the districts of Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad, and Parbhani.

12. The following table shows the summary of the number of roads and the corresponding length in every district.

Table1. Distribution of the target rural roads for the Maharashtra Rural Connectivity Improvement Project – Additional Financing

District	ROADS	
	No of Roads	Length (Km)
Akola	37	116.51
Amaravati	24	73.01
Washim	24	58.95
Buldhana	33	61.58
Yavatmal	32	74.90
Amaravati Region	**150**	**384.94**
Osmanabad	63	132.26
Nanded	34	68.69
Hingoli	30	79.88
Beed	37	132.00
Latur	32	80.45
Parbhani	40	96.15
Aurangabad	35	107.30
Jalna	34	127.85
Aurangabad Region	**305**	**824.57**
Raigad	23	61.61
Palghar	23	57.58
Sindhudurg	24	64.83
Ratnagiri	48	106.20
Thane	10	19.47
Konkan Region	**128**	**309.68**
Nagpur	27	115.66
Chandrapur	15	64.11
Wardha	28	90.65
Bhandara	18	76.72
Gadchiroli	2	9.78
Gondia	34	84.58
Nagpur Region	**124**	**441.50**
Ahmednagar	66	167.51
Nandurbar	17	68.19
Dhule	20	70.90
Jalgaon	33	107.29
Nashik	39	101.92
Nashik Region	**175**	**515.81**
Satara	36	80.90
Kolhapur	32	57.96
Sangli	38	92.93
Solapur	45	124.52

[7] Large igneous province on the Deccan Plateau of west-central India.

Pune	67	132.28
Pune Region	**219**	**489.60**
Maharashtra	**1100**	**2965.07**

Bridges

13. The proposed bridges are designed according to the (i) specifications for rural roads (2004), (ii) Indian Road Congress (IRC):SP:20 (2002)[8], (iii) IRC:SP13:2004[9], (iv) IRC:SP:82:2008[10] and (v) Guidelines for Bridge Designs by the Designs Circle of Public Works Department (PWD), Maharashtra.

14. Similar to the roads, the target bridges are located within the 6 regions of the state. The length of these bridges ranges from 6 m. to 126m. Aurangabad has the most number at 61 target bridges that are located in 8 districts. These are in (i) Aurangabad, (ii) Beed, (iii) Hingoli, (iv) Jalna, (v) Latur, (vi) Nanded, (vii) Osmanabad, and (viii) Parbhani. While Pune Region has the least number of target bridges at 15 in the districts (i) Pune, (ii) Sangli and (iii) Solapur.

15. The following table shows the summary of the number of roads and the corresponding length in every district.

Table 2. Distribution of the target bridges for the Maharashtra Rural Connectivity Improvement Project – Additional Financing.

District	**Bridges**	
	No. of Bridges	**Length of Bridges (m)**
Akola	8	496.00
Amaravati	12	510.00
Washim	8	293.00
Buldhana	3	161.00
Yavatmal	2	66.00
Amaravati Region	**33**	**1526.00**
Osmanabad	13	596.00
Nanded	16	558.60
Hingoli	2	99.00
Beed	6	474.26
Latur	7	328.00
Parbhani	4	276.00
Aurangabad	7	443.00
Jalna	6	228.00
Aurangabad Region	**61**	**3002.86**
Raigad	5	160.00
Palghar	8	268.90

8 Indian Road Congress: Rural Roads Manual
9 Indian Road Congress: Guidelines for the Design of Small Bridges and Culverts
10 Indian Road Congress: Guidelines for Design of Causeways and Submersible Bridges

Sindhudurg	5	184.00
Konkan Region	**18**	**612.90**
Nagpur	3	198.00
Chandrapur	9	455.00
Wardha	19	645.00
Bhandara	9	458.00
Gadchiroli	2	80.00
Gondia	12	548.00
Nagpur Region	**54**	**2384.00**
Ahmednagar	7	288.00
Nandurbar	8	594.00
Dhule	12	588.00
Jalgaon	20	793.00
Nashik	8	406.00
Nashik Region	**55**	**2669.00**
Sangli	1	55.00
Solapur	12	571.80
Pune	2	119.02
Pune Region	**15**	**745.82**
Maharashtra	**236**	**10940.58**

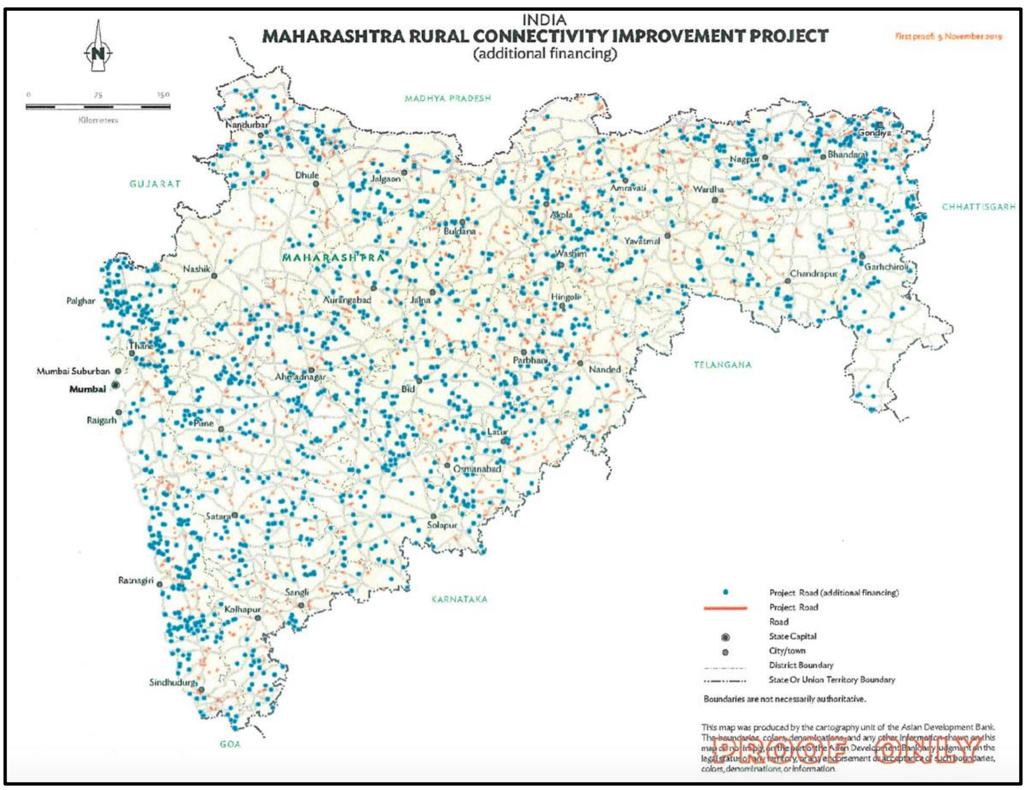


Figure 1: Locations of the proposed rural roads under the Maharashtra Rural Roads Connectivity Project Additional Financing.

III. CLIMATE CONDITION AND TRENDS

Baseline assessment

Topography

16. W*estern Ghats*. Known as the Sahyadri Range in the states of Maharashtra, Karnataka and the Malabar, the Western Ghats is the most visible natural structure in the region and forms the backbone of the state. At Mahabaleshwar (1438 m), the altitudes of the ranges are higher in the northern parts of the state. The range extends northward to the Tapti River and southward almost to India's southern tip. Elevations of the mountains reach 900 to 1,500 meters in the north and reaching 2,637 meters at Doda Betta mountain.

17. Western Ghats is a very important part of the physiology of the state because it blocks the monsoon bearing winds and causes rainfall in the eastern part. The Western Ghats receive heavy rainfall from the southwest monsoon and precipitation is much lighter inland on the plateau. With bamboo, teak, and other valuable trees, high rainfall produced dense forests on the seaward slopes. The ranges form the most important drainage basin for the river systems of western and central India.

18. *Deccan Plateau*. The altitude of the plateau may vary from 450 - 750 m. It covers most of the peninsular part of the country, which is bordered by the Western Ghats and the Eastern Ghats. Most of the northern part of the Deccan is covered by Maharashtra. Pune, Nagpur and Solapur are the major cities of Maharashtra in the Deccan region. Formed by the volcanic activities the rocks are of igneous types, the rocks of this region are mainly basalt and granite.

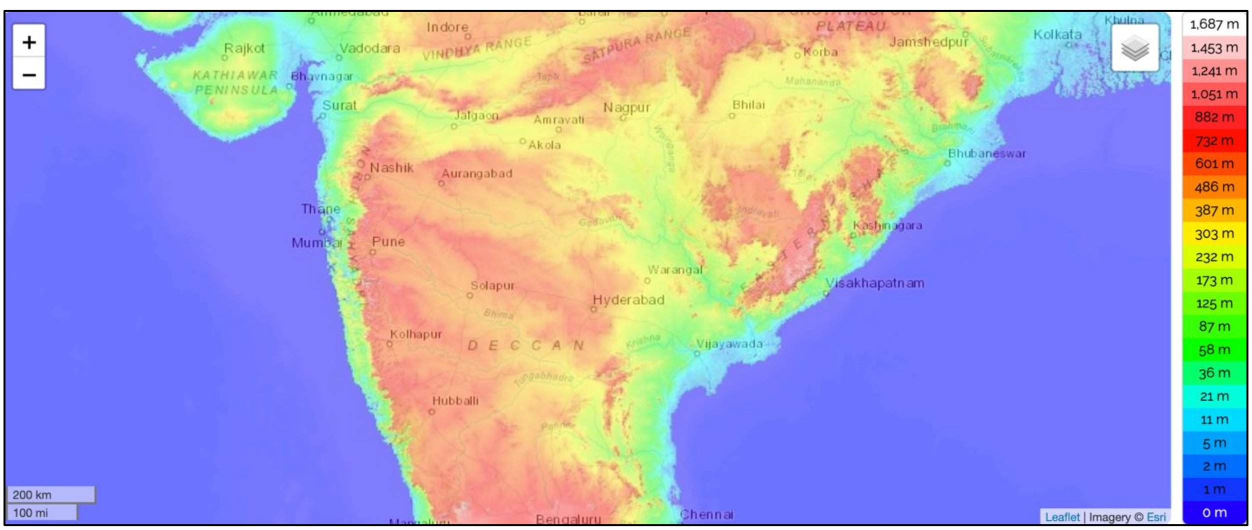


Figure 3. Maharashtra topographic map, which maximum elevation is 1,827 and average elevation is 308 m[11].

19. *Hills*. Main hills and ranges of the region include Satpura range and the Tamhini, Varandha and the Sawantwadi Ghats. The Satpuda Range and the Bhamragad-Chiroli-Gaikhuri ranges form a chain of mountain ranges in the eastern part of the state. The Satpura Ranges originate at the eastern part of Gujarat and pass through the states of Maharashtra, Madhya Pradesh and Chhattisgarh. These hills have been cleared for inhabitation even though the range was formerly covered with heavy forests.

20. *Coastal Belts*. The Konkan coastal region stretches from the states of Gujarat to Kerala and lies to the west of the Western Ghats. The maximum altitude of the region is mostly below 200 m. Mainly a lowland area, the Konkan coastal region is situated between the Arabian Sea and the Sahyadri range. The region is very unruly, steep at some places and at some places a valley region.

21. *River Valleys.* Main rivers of the state and their tributaries run across the plateaus. The rivers Krishna, Bhima, Godavari, Tapi - Purna and the Wardha - Wainganga formed important features on the surface of the land. Krishna River rises from an elevation of 1,337 m. north of Mahabaleshwar. Godavari River starts from Nashik in Maharashtra, which is at the elevation of 1,465 km. It flows nearly around 1,465 km and discharges to Bay of Bengal. Tapi River starts at 752 m. near Multai in the Betul district of Madhya Pradesh and flows for 724 km to the Arabian Sea. The river basins in the western part are the Konkan Rivers basin, the Tapi River Basin and the Narmada River Basin. Those that are on the eastern side are the Krishna and the Godavari river basins.

Observed Rainfall Trend

22. This CRVA used the results of the study by Potdar, et al (2019). “The long-term trend analysis of rainfall data from 1901 to 2015 for Maharashtra and Goa region from India”. The article provided the long-term trend analysis of annual and southwest (SW) monsoon rainfall over Maharashtra and Goa region, which covered the years from 1901–2015. The study divided the region into four meteorological subdivisions, with homogeneous climate distinct with the others, across the Maharashtra and Goa, namely, (i) Konkan and Goa; (ii) Madhya-Maharashtra; (iii) Marathwada; and (iv) Vidarbha. According to the study, the well-known linear regression analysis, Mann-Kendall (MK) analysis test and Sen’s slope estimator methods are used to detect the trend and its significance.

[11] https://en-in.topographic-map.com/maps/gmh5/Maharashtra/

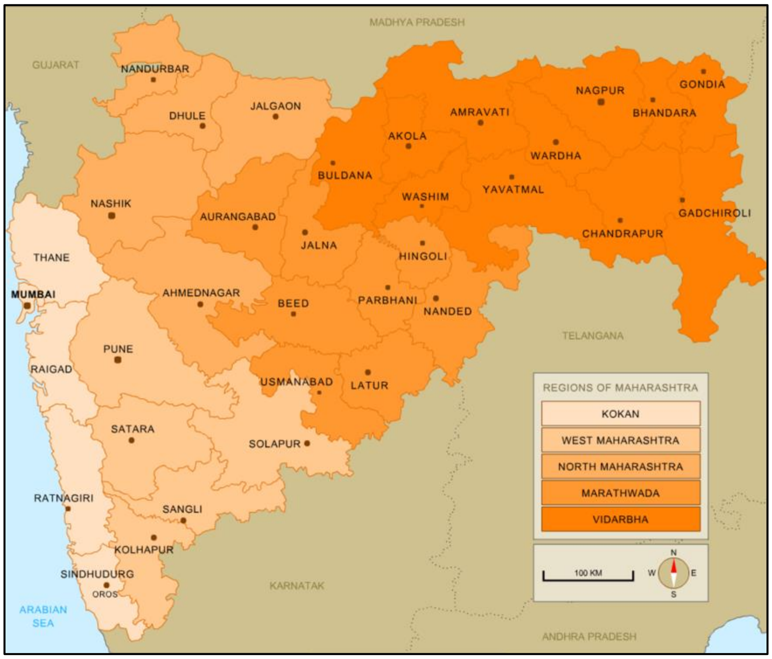


***Figure 4. Meteorological Subdivisions Map*[12]**

Table 3. Coverage of the meteorological subdivisions

Meteorological Subdivisions	Area (km^2)	Divisions	Districts-wise locations of the project
Konkan and Goa	34,095	Konkan	Raigad
			Palghar
			Sindhudurg
Madhya-Maharashtra	115,306	Pune	Sangli
			Solapur
			Pune
		Nashik	Ahmednagar
			Nandurbar
			Dhule
			Jalgaon
			Nashik
Marathwada	64,525	Aurangabad	Osmanabad
			Nanded
			Hingoli
			Beed
			Latur
			Parbhani
			Aurangabad
			Jalna
Vidarbha	97,536	Nagpur	Nagpu
			Chandrapur
			Wardha
			Bhandara

[12] https://commons.wikimedia.org/wiki/File:Gr_Wiki_MH_Regions_96ppi.png

			Gadchiroli
			Gondia
		Amaravati	Akola
			Amaravati
			Washim
			Buldhana
			Yavatmal

Konkan Division (Konkan and Goa Region)

23. As compared to the other subdivisions, Konkan and Goa Region (Konkan Division) receives the maximum rainfall in the entire state. Located at the costal region at western site of Maharashtra, this area receives rainfall of about 50% of total rainfall of the Maharashtra. Southwest monsoon splits into two branches, the Arabian Sea Branch and the Bay of Bengal Branch near the southern coastal region over Indian peninsula. The Arabian Sea Branch of the southwest monsoon is blocked by the Western Ghats, where clouds are stopped by mountains.

24. Along with linear fit, the time series of annual and southwest monsoon rainfall over Konkan Division for the period 1901 to 2015 is shown in Figure 5. Konkan Division's mean annual and southwest monsoon rainfall is about 2,978 mm and 2,794 mm, respectively. Figure 5 shows long-term linear trend in the annual and southwest monsoon rainfall data shows increasing nature.

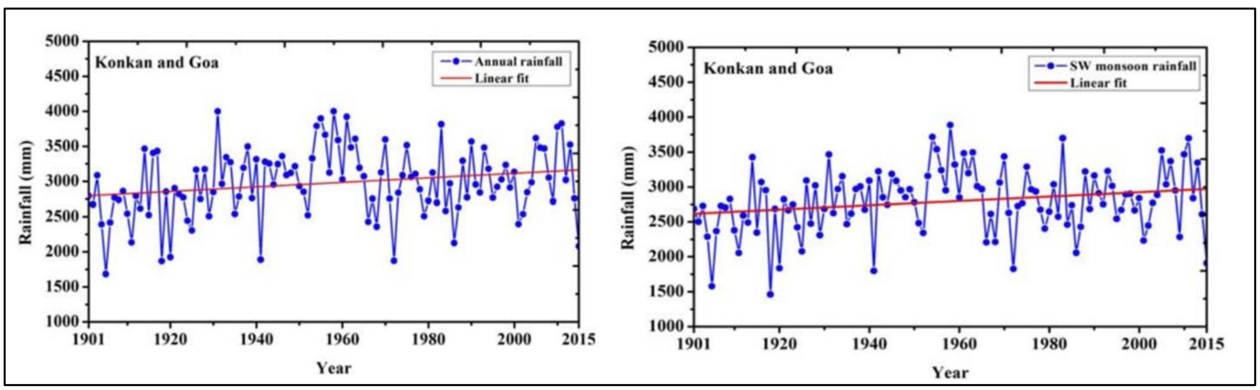


Figure 5. The time series of (a) annual rainfall and (b) SW monsoon rainfall (lower panel) with linear fit over Konkan and Goa Region for the period of 1901 to 2015[13]

Pune and Nashik Divisions (Madhya-Maharashtra Region)

25. From 1901 to 2015, the annual and southwest monsoon rainfall over Pune and Nashik Division is in the figure below. According to the study, the mean annual and southwest monsoon rainfall is about 980 mm and 738 mm, respectively. Both annual rainfall and southwest monsoon rainfall shows increasing trend over the divisions. Increasing trend of the southwest monsoon is higher than the annual rainfall of the region.

[13] Figure 3, The long-term trend analysis of rainfall data from 1901 to 2015 for Maharashtra and Goa region from India

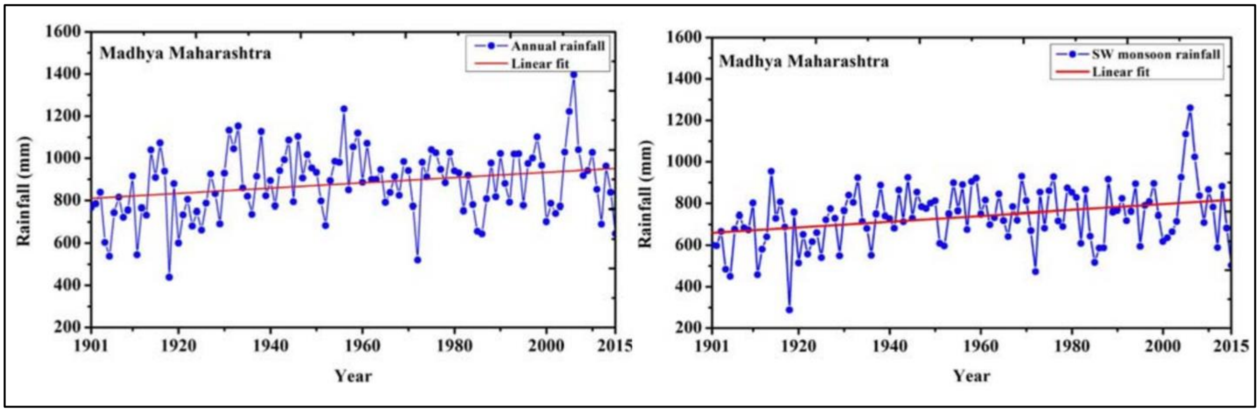


Figure 6. The time series of (a) annual rainfall and (b) SW monsoon rainfall (lower panel) with linear fit over Madhya-Maharashtra Region for the period of 1901–2015[14]

Aurangabad Division (Marathwada Region)

26. Aurangabad Division receives lowest rains as compared to other regions. Mean annual rainfall (790 mm) and southwest monsoon rainfall (662 mm). The southwest monsoon contributes of about 83% in annual rainfall over Aurangabad. In Figure 7, the annual rainfall and southwest monsoon rainfall shows decreasing trend over Marathwada meteorological region.

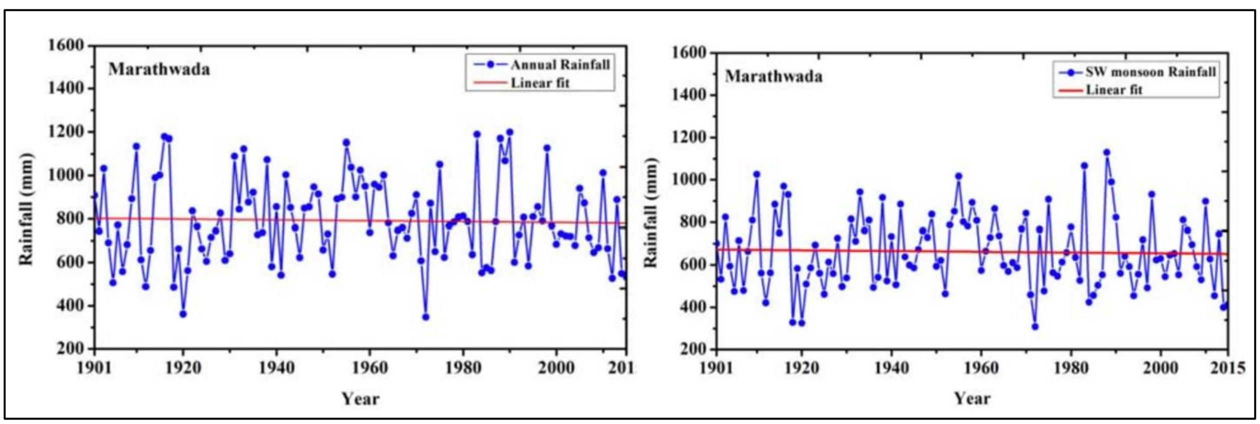


***Figure 7.* The time series of (a) annual rainfall and (b) SW monsoon rainfall (lower panel) with linear fit over Marathwada Region for the period of 1901–2015[15]**

Nagpur and Amaravati Divisions (Vidarbha Region)

27. The divisions of Nagpur and Amaravati is also considered to be drought region in Maharashtra. With linear fit for the period 1901 to 2015, rainfall trend of the annual and southwest monsoon rainfall is as shown in Figure 8. Mean annual and southwest monsoon rainfall is 1,095 mm and 964 mm, respectively. This shows southwest monsoon contributes about 88% in the annual rainfall over this region. Similar to Marathwada Region, both the annual rainfall and southwest monsoon rainfall shows decreasing a trend throughout the analysis.

---

[14] Figure 4, The long-term trend analysis of rainfall data from 1901 to 2015 for Maharashtra and Goa region from India
[15] Figure 5., The long-term trend analysis of rainfall data from 1901 to 2015 for Maharashtra and Goa region from India

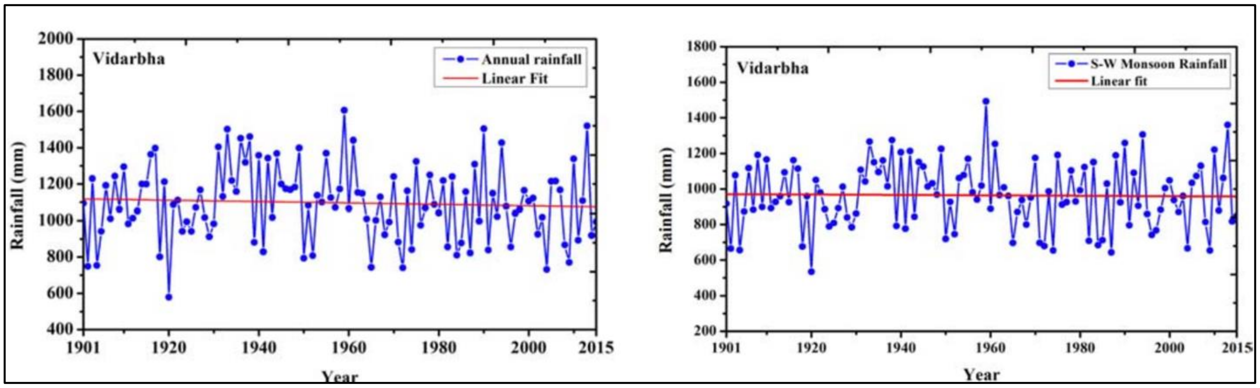


Figure 8. The time series of (a) annual rainfall and (b) SW monsoon rainfall (lower panel) with linear fit over Marathwada Region for the period of 1901–2015[16]

Temperature

28. The climate of Maharashtra involves different weather conditions across a wide geographic scale and topography, hence, generalizations difficult for the state. Using the Köppen system[17], Maharashtra hosts 4 major climatic subtypes, semi-arid (Bsh), tropical savanna (Aw), area of tropical monsoon (Am) and (iv) Mediterranean climate (Csa). Only Bsh and Aw are accounted for the CRVA because the locations of the of the rural roads and bridges are within these climatic regions. Semi-arid is the climate of a region that receives rainfall below the potential evapotranspiration, but not as low as a desert climate. Tropical Savannah have monthly mean temperature above 18°C in every month of the year and typically a pronounced dry with the driest month having less than 60 mm of precipitation.

29. In this report, the information from climate-data.org are used to define the state's historical temperature in different distrcits. The temperature data from the website utilized the historical records from 1982 to 2012. Based on the Köppen system, divsions of Pune, Aurangbad, Solapur, Amravati and Sangli are under semi-arid climate, while Mumbai, Nagpur and Nashik are classified as tropical savanna region.

30. Average temperature for these divisions is shown on Table 4. The average temperature for all divisions will peak on the month of May that started to rise on the month of February. Average temperature for all the divisions appear to be stable from the July to October. Among all the divisions, Nagpur experiences highest average temperature and lowest as well.

Table 4. Average monthly historical temperature (°C) in different parts of the state.

Location	Climate	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pune	Bsh	21.3	23.1	26.3	29	29.6	27.3	24.8	24.5	24.8	25.5	23	21.1
Aurangabad	Bsh	21.6	24	27.8	31	32.4	28.9	25.8	25.2	25.3	25.4	23.1	21.3
Solapur	Bsh	23.2	25.5	29.1	31.8	32.9	29.3	26.9	26.6	26.5	26.5	24.1	22.4

[16] Figure 6, The long-term trend analysis of rainfall data from 1901 to 2015 for Maharashtra and Goa region from India
[17] The Köppen Climate Classification System is the most widely used system for classifying the world's climates. Its categories are based on the annual and monthly averages of temperature and precipitation.

Amaravati	Bsh	22.1	24.5	28.8	32.5	35.1	31.5	27.1	26.6	26.8	26.5	23.8	21.9
Sangli	Bsh	22.5	24.3	27.2	29.6	29.8	26.9	24.6	24.3	24.9	25.5	23.4	22.1
Mumbai	Aw	23.7	23.9	26.2	28.1	29.7	28.9	27.2	26.8	27	28	27	25.1
Nagpur	Aw	20.7	23.4	28.1	32.5	35.3	31.5	27.6	27.1	27.6	26.2	22.7	20.1
Nashik	Aw	20.4	21.8	25.3	28.3	29.5	27.6	25.1	24.7	24.6	25	22.7	20.8

Bsh: semi-arid, Aw: Tropical Savanna

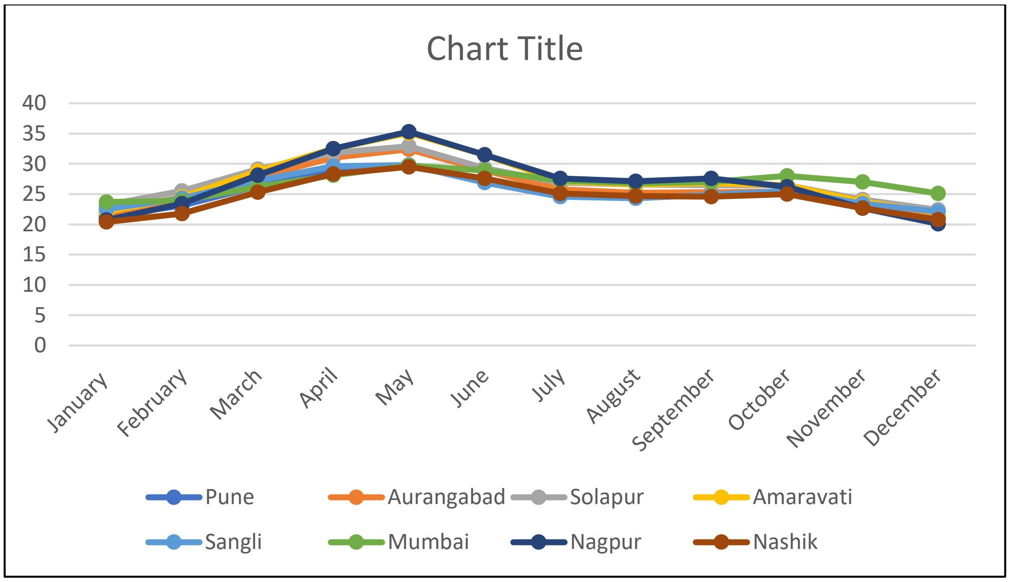


Figure 9. Average temperature from 1985-2015 records in different parts of Maharashtra[18]

Flooding Events

31. On August 2019, torrential rains in western areas has worsened the flood situation in Maharashtra. According to India Meteorological Department (IMD), several parts of the state recorded high amount of rainfall such as in Dungerwadi (450 mm), Tamini (430 mm), Dawdi (420 mm), Shirgaon (370 mm), Bhira (330 mm), Roha (290 mm), Mahabaleshwar (280 mm) and Pauni (270 mm). India's Central Water Commission Official Flood Forecast announced that the extremely heavy rainfall in Maharashtra caused many of the rivers in Thane, Raigad, Pune, Nasik, Ratnagiri and Palghar districts to overflow and inundate lands.

32. The 2019 flood in western Maharashtra has devastated hundreds of villages, damaging property and 16 lives lost (Press Trust of India). Thousands of people have been evacuated from Sangli, Satara, and Kolhapur to safer places. In Western Maharashtra, over 1.32 lakh people have been shifted to safer places with the flood situation remaining grim in Kolhapur and Sangli districts. Over 53,000 people evacuated in Sangli, 51,000 in Kolhapur and around 6,000 in Satara. Further, 2,500 people were evacuated from Solapur, and 340 bridges were underwater and closed for vehicles. Around 30 state highways and 56 roads were closed to prevent further

[18] https://en.climate-data.org/asia/india/maharashtra-747/

accidents. All dams in Pune, Satara, Sangli and Kolhapur reached full capacity, thus authorities alerted all riverside villages. The damage to infrastructure was estimated to be in over Rs 100 crores.

33. From the accounts by the State of Environment Report: Maharashtra, inundation mainly result from damage to the dam embankments, release of excessive water from dams, improper storm-water drainage systems and unplanned urbanization[19]. The rivers, which cause flood in the State are the Tapi, Wardha and occasionally the Pen-Ganga. The eastern parts of the State are prone to floods. More than two lakh hectares of land in Maharashtra is prone to floods and Patur taluka in Akola district has the largest flood prone area in the State. Nanded and Nashik are frequently affected by floods in the monsoons. Chandori, Saikheda and Niphad are the three major flood-prone areas in Nashik district. The following table is the summary of ENVIS' study on the susceptibility of different location in Maharashtra on flooding.

Table 5. Maharashtra's district-wise flooding risks based on the State's Environment Report.

District	Flooding History
Ahmednagar	Three per cent of the population lives in flood prone areas
Akola	Patur taluka has the largest flood-prone area (57%), followed by Barsi Takli (48%), Akot (45%), Balapur (40%)
Amravati	Flood-prone along the Wardha river; eight floods in the last 15 years
Aurangabad	Small floods (Ranks 3 in the district disaster management plan)
Beed	Flood-prone: almost 26 % of the population lives in flood-prone areas
Bhandara	Flood-prone along the Vainganga river
Chandrapur	Flood-prone
Dhule	170 villages identified as flood-prone every year
Gadchiroli	Three major floods in the last 10 years; 9.89 % of the population lives in flood-prone areas
Jalna	7 floods in the last 30 years; 196 villages flood prone
Kolhapur	Severe floods in 1989 and 1994; 188 riverside villages are prone to flood
Nagpur	Flood-prone during monsoons. Seven major floods in the last 30 years. 13 % of the population lives in flood-prone areas.
Nanded	History of frequent floods due to heavy rainfall and release of water from irrigation projects
Nashik	Three major flood-prone areas: Chandori, Saikheda, Niphad; 38.33 % of the population lives in flood-prone areas
Parbhani	Medium probability, based on rainfall
Pune	Yes
Raigad	Yes
Ratnagiri	Possibility of river floods in the monsoons
Sangli	Flood-prone.
Satara	Possible monsoon floods
Sindhudurg	Prone to floods due to high rainfall and rush of seawater during high tide

[19] http://mahenvis.nic.in/pdf/Soer/soer_soer8.pdf

Solapur	Possibility of floods. Major flood on the Bhima river
Thane	Yes
Wardha	Great threat of floods
Yavatmal	Heavy floods in 1994

Drought Hazard Susceptibility

34. The State of Maharashtra is a drought-prone state. Around 70% of the Maharashtra's geographical area with-in semi-arid region, making the state vulnerable to water scarcity. Frequently, almost all the districts in the divisions of Pune, Aurangabad, and Nashik divisions are experiencing drought frequently. Most of the state's talukas under the Drought Prone Area Programme (DPAP) are in these districts. These talukas receive rainfall that ranges from 600 to 750 mm during the southwest monsoon or months of June to October. The evaporation rate is high, and only in the month of September when the precipitation exceeds evaporation.

35. Small amount of monsoon rains affect both the Kharif and Rabi crops in drought prone areas. Aside from poor rainfall, unevenness of rains within the monsoon months (long dry spells) affects the crop production. In many parts, hard basalt rock in the region does not allow filter or storage of water. Therefore, when there is scanty rainfall, the scarcity of water both for drinking water and cultivation is acute.

36. Severe drought conditions occur once every 8–9 years. Maharashtra experienced severe and successive years of drought in 1970–1974 and 2000–2004 (World Bank, 2008). Due to regular drought frequency, low levels of irrigation coverage, literacy, and infrastructure development and poor coping & adaptive capacity, this region is highly vulnerable to impacts of climate change.

37. In 2012, the State received lower rainfall during the months of June to September 2012, which resulted in the 2013 drought. This was the worst drought to hit the region in 40 years. The worst-hit are Solapur, Ahmednagar, Sangli, Pune, Satara, Beed and Nashik. Residents of Latur, Osmanabad, Nanded, Aurangabad, Jalna, Jalgaon and Dhule districts.

38. Monsoon has hit Maharashtra hard in 2019, not just because of excess rains, but also due to lack of rainfall. While thousands of people in Satara, Sangli, Kolhapur and other neighbouring areas were trying to gather their lives together after the flood, residents in Beed are reeling under severe drought-like conditions. Rain deficiency caused the water supply from dam nearly dried and affected kharif sowing in the state. It was reported that more than 80 lakh farmers were affected with drought conditions.

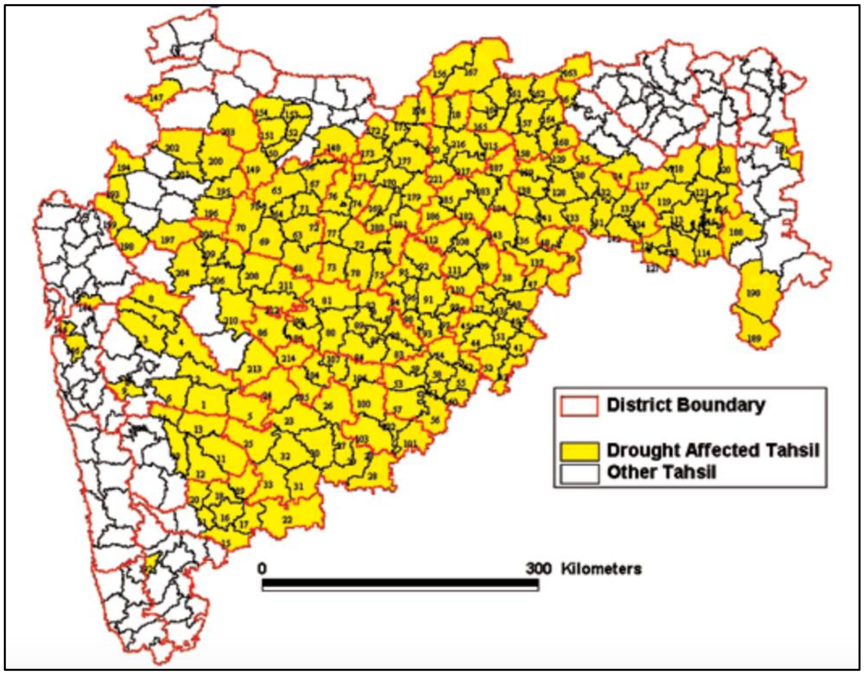


Figure 10. Map of the drought prone areas in Maharashtra[20]

Cyclones Trends

39. Maharashtra has a coastal belt of over 720 kilometers and coastal areas are risk-prone to cyclones. Therefore, the Konkan region including Mumbai is prone to tropical cyclones. The risks from cyclones have large impact on the sector of marine fishing villages along the coastal belt. It may also affect the irrigation infrastructure, and transport and communication that can receive serious infrastructure damages.

40. Traditionally, it has been the eastern coast of India that has been majorly vulnerable to cyclones. Located at the western coast of the country, the state's geographical location, climatological conditions and other natural factors put Maharashtra under moderately vulnerable category as far as cyclones are concerned. As shown on the map below, districts of Thane, Raigad and Ratnagiri are vulnerable to cyclones at western area of the state. Districts of Nagpur, Chandrapur, Wardha, Bhandara, Gadchiroli, and Gondia, and Yavatmal in Amravati are prone to cyclones coming from the Bengal Bay.

[20] https://rfd.maharashtra.gov.in/sites/default/files/DM%20Plan%20final_State.pdf

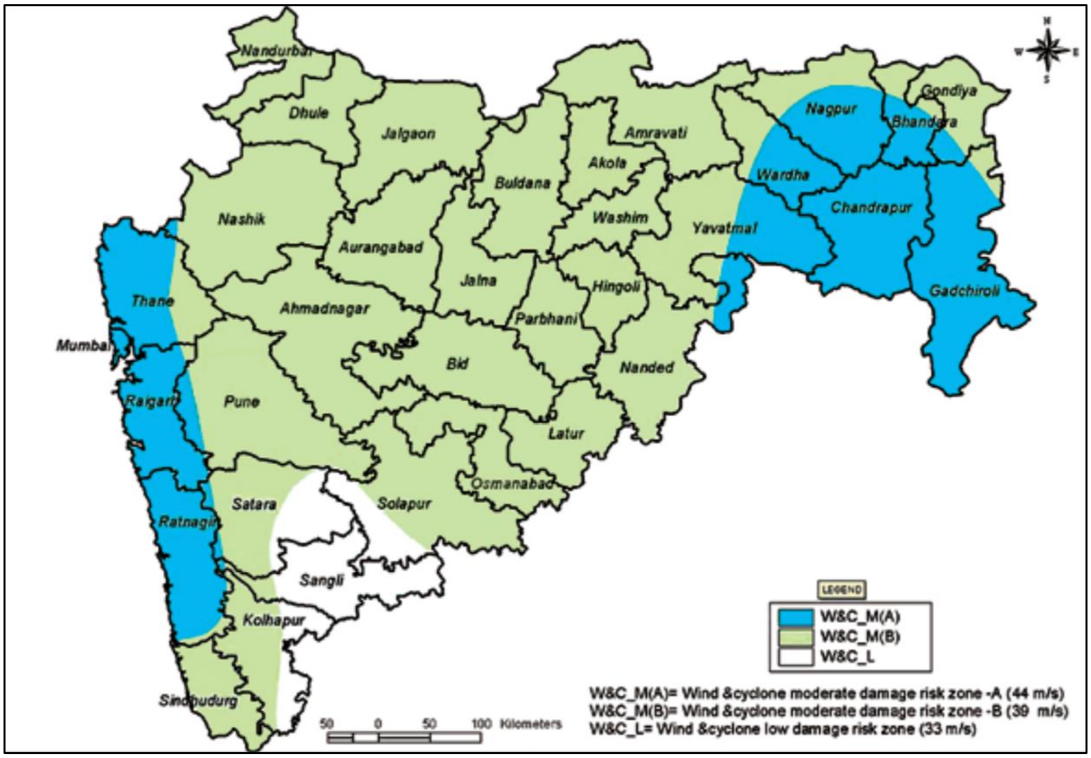


Figure 11. Map of Maharashtra that shows the affected areas by previous cyclones[21]

IV. CLIMATE RISK AND VULNERABILITY ASSESSMENT

Climate Hazards

Summary of Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra

41. As a pioneering step, The Government of Maharashtra prepared the Maharashtra State Adaptation Action Plan on Climate Change (MSAAPCC) through a comprehensive vulnerability assessment study called "Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra". The study included generation of model-based climate projections specific to the State's geography and broadly aimed to address the urgent need to integrate climate change concerns into the State's overall development strategy. Therefore, assisting in building long term climate resilience and enabling adaptation to the likelihood of risks arising from climate change.

42. Developed by the UK Met Office, high resolution HadRM3P model in the Providing Regional Climate Studies (PRECIS) Regional Climate Modelling System and a unique domain1 selection method are used to represent the climatic pattern at a resolution of 25 km^2, such as changes in temperature and rainfall projections. The projections are related to three future time slices 2030s, 2050s, and 2070s, with respect to the model baseline, which was the average climate during 1970-2000. The model results were validated using several observational datasets of the India Meteorological Department (IMD) 1x1 degree gridded data rainfall data from 1951–2007 and mean, maximum, and minimum temperature records from 1969–2005. Daily mean climatologies of district wise datasets (IMD, 2010) of number of rainy days, maximum

[21] https://rfd.maharashtra.gov.in/sites/default/files/DM%20Plan%20final_State.pdf

temperature, minimum temperature and mean temperature values have been used to assess the district wise variation in the number of rainy days during June, July, August, and September and the variability in temperature.

43. The results of the climate modelling show that temperature and rainfall projections will increase all over the state, but with regional variations. The projected rise in mean temperature is highest for the 2070s compared to the 2050s and 2030s. According to the models, Amravati and Aurangabad divisions may experience a higher rise in annual mean temperature than other areas of Maharashtra. By the 2030s and 2050s, the projected increase in monsoon rainfall is relatively more for Amravati and Nashik divisions. Divisions like Konkan and Nagpur are projected to receive, more rainfall. This overall increase in monsoon rainfall for the state is consistent with the findings of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[22].

44. Table 6 shows the projected increases in mean temperature and average monsoon rainfall over Maharashtra. The projection for the 2030s is the average of projections for the period 2021-2040. Similarly, the projection for the 2050s in the average of projections for 2041-2060 and that for the 2070s is the average of projections for 2061-2080

Table 6. projected increases in mean temperature and average monsoon rainfall according to the Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra Report

Division	IMD climate normal: annual mean temperature (ºC)	Projected increase in annual mean temperature (ºC)			IMD climate normal: monsoon rainfall (mm)	Projected increase in monsoon rainfall (%)		
		2030’s	2050’s	2070’s		2030’s	2050’s	2070’s
Amravati	27.21	1.44-1.64	2.2-2.35	3.06-3.46	785.3	17.5-30	22.5-32.5	15-27.5
Aurangabad	26.46	1.44-1.56	2.15-2.3	3.14-3.38	708.8	12.5-27.5	15-30	20-40
Nashik	26.79	1.4-1.68	2-2.4	2.82-3.3	567.5	17.5-40	15-40	15-52.5
Nagpur	27.19	1.18-1.4	1.95-2.2	2.88-3.16	1124.7	12.5-20	12.5-30	15-27.5
Pune	25.22	1.15-1.28	1.65-1.95	2.46-2.74	852.2	10-32.5	10-32.5	12.5-37.5
Konkan	26.99	1.1-1.28	1.5-1.8	2.18-2.6	2578.2	10-30	10-30	10-32.5

Climate Change Projections Based on CMIP5 and RCP8.5

45. Projection of temperature and rainfall changes in the State is provided by means of World Bank’s Climate Change Portal 2.0 is referenced from the Maharashtra RCIP’s CRVA. Tables 7 and 8 present the temperature and rainfall projection based on the Beijing Climate Center Climate System Model (bcc-csm_1). The projected change in temperature and rainfall were derived using the representative concentration pathways 8.5. Historical records were compiled by the Climate Research Unit, University of East Anglia from 1986–2005. The significant findings are as follows:

(i) The State is expected to experience a general increase in average monthly temperature from 0.68ºC in Nagpur to 0.79ºC in Nashik Region. Konkan and

[22] IPCC Working Group 1 Technical Summary Section TS.5.8.1 and Table TS.2

Nashik may experience higher temperature increase compared to the other regions.

(ii) Highest increase in average monthly temperature are expected in Nagpur and Amravati with 1.45ºC and 1.43ºC during the month of October.

(iii) The project will experience an increase in rainfall. The highest annual average increase is expected in Konkan and Nagpur regions.

(iv) Substantial increase in monthly rainfall may occur during the months of June and August across the State. Higher increase in monthly rainfall are expected in Nagpur and Konkan which could register 89% and 78% higher than historical averages.

46. Although downscaled global climate models are in agreement on the increasing trend of monsoon rainfall, the distribution is not linear in between the months of June, July, August, and September. Patil[23] et. al (2013) assessed trend of rainfall in Pune District using 47 years (1958–2004) data from 13 observatories pertaining to annual, seasonal (kharif) and monthly rainfall depths during kharif season using non-parametric Mann-Kendall (MK) test and modified Mann-Kendall (MMK) trend test. The study revealed "seasonal (Kharif) rainfall was observed to be decreasing and June month's rainfall showed increasing trend while July month's rainfall showed decreasing trend at 99%, 95% and 90% level of significance, respectively. The decreasing trend of rainfall was observed during July month for the rainfall gauging stations under high rainfall zone (Welhe-99%, Mulshi-95%andMaval-95%) and medium rainfall zone (Bhor-99%, Ambegaon-99%, Junnar-95%, Khed-99%, Pune-99% and Purandhar-99%) of Pune district."

Table 7: Historical and Projected Increase in Temperature (ºC), CMIP5 and RCP8.5

Month	Nashik		Aurangabad		Amravati		Nagpur		Konkan		Pune	
	Hist	PI	Hist	PI	Hist	PI	Hist	PI	Hist	PI	Hist	PI
Jan	20.62	1.17	21.55	1.11	21.61	0.92	21.16	0.81	23.19	0.87	20.88	1.04
Feb	22.22	0.89	23.68	0.89	24.32	0.81	23.96	0.84	24.25	1	22.54	0.95
Mar	25.84	0.92	27.54	0.91	28.55	0.73	28.25	0.67	26.54	0.81	25.9	0.88
Apr	28.89	0.98	30.82	0.97	32.48	0.77	32.35	0.76	28.44	0.91	28.81	0.96
May	30.16	0.98	32.2	1.07	34.73	1.18	35.11	1.14	29.05	0.73	29.92	0.15
Jun	27.99	0.16	29.34	-0.1	31.67	-0.39	32.12	-0.42	26.61	0.16	27.58	0.65
Jul	25.61	0.54	26.59	0.48	27.65	0.24	28.06	0.26	25.21	0.77	27.47	0.65
Aug	24.57	0.86	25.66	0.8	26.53	0.39	27.05	0.26	24.83	0.8	24.75	0.83
Sep	25.33	0.03	26.21	-0.16	27.17	0.33	27.58	0.28	25.31	0.48	25.25	0.19
Oct	25.63	1.07	26.35	1.25	26.79	1.43	26.59	1.45	25.88	1.12	25.44	1.1
Nov	23.35	0.88	23.91	0.95	24.17	1	23.52	0.99	25.04	0.93	23.26	0.89
Dec	20.93	1.02	21.35	1.06	21.49	1.09	20.77	1.08	23.37	0.9	20.77	1.02
Mo Ave	***25.10***	***0.79***	***26.27***	***0.77***	***27.26***	***0.71***	***27.21***	***0.68***	***25.64***	***0.79***	***25.21***	***0.78***

Hist = Historical, PI = Projected Increase, Mo Ave = Monthly Average

Table 8: Historical and Projected Increase in Rainfall (mm), CMIP5, RCP8.5

Month	Nashik	Aurangabad	Amravati	Nagpur	Konkan	Pune

[23] Patil, Jyoti & Sarangi, A & Singh, D.K. & R Rao, A & Dahiya, Shashi. 2013. Rainfall trend analysis: A case study of Pune district in western Maharashtra region. Journal of Soil and Water Conservation. 12.

	Hist	PI	Hist	PI	Hist	PI	Hist	PI	Hist	PI	Hist	PI
Jan	1.57	4.53	4.72	9.37	4.72	9.37	13.38	0.47	0	0.06	1.03	6.65
Feb	0.48	1.68	1.33	0.65	1.33	0.65	16.8	-0.34	0.16	-0.76	0.63	1.7
Mar	1.33	3.58	2.73	5.38	2.73	5.38	20.08	-1.93	2.19	0.27	1.05	3.89
Apr	2.83	1.02	2.66	1.65	2.66	1.65	8.07	8.99	17.1	1.78	6.92	1.33
May	19.32	1.56	20.43	1.62	20.43	1.62	16.07	1.34	37.39	6.57	26.08	2.46
Jun	138.05	58.77	150.51	65.43	150.51	65.43	168.2	52.98	345.57	74.51	173.78	73.13
Jul	231.51	-12.62	154.38	-13.09	154.38	-13.09	297.68	32.55	439.2	111.51	195.2	-16.67
Aug	193.21	55	152.08	45.99	152.08	45.99	284.44	32.45	277.43	170.21	151.14	64.79
Sep	178.57	15.58	147.89	19.7	147.89	19.7	165.4	21.6	166.16	66.02	156.09	5.42
Oct	56.52	-11.82	53.51	15.82	53.51	-15.82	62.75	12.84	100.79	6.22	70.75	-12.85
Nov	8.53	0.34	14.75	-0.37	14.75	-0.37	14.1	0.5	19.62	10.35	11.86	-0.63
Dec	6.27	-1.59	11.81	-1.1	11.81	-1.1	12.72	4.06	9.8	10.36	10.09	-1.89
Mo Ave	***69.85***	***9.67***	***59.73***	***12.59***	***59.73***	***9.95***	***89.97***	***13.79***	***117.95***	***38.09***	***67.05***	***10.61***

Hist = Historical, PI = Projected Increase, Mo Ave = Monthly Average

Sensitivity and Exposure Assessment

47. In 2015, ThinkHazard![24] project was initiated to have easier access to hazard information and risk management guidance for development sector professionals. It is an open access website that enables users to screen potential project locations for the existence of multiple natural hazards and any impacts of their project on the local hazard. It is an analytical tool to improve knowledge and understanding of natural hazards. Also, the benefits of ThinkHazard! is the general education about global distribution of multiple hazards and how to manage them. The following sections are the potential climate risks on Maharastra's districts by using the web-based tool.

Extreme Heat

48. Based on an existing and widely accepted heat stress indicator, the Wet Bulb Globe Temperature (WBGT, in °C) is used by the analytical tool to classify the extreme heat hazard. Obviously, the WBGT has relevance to human health, but it is relevant in many kinds of projects, including infrastructure related heat stress to the design of roads and bridges. In general, the WBGT is relevant enough to quantify the strain on physical infrastructure. The heat stress thresholds that make use of the WBGT apply the following classification: (i) high: >32°C, (ii) medium: >28°C, (iii) low: >25°C and (iv) very low: <25°C.

49. For extreme heat events, there are no standard return periods used in engineering designs, but for the tool, the return period is a factor on classifying the heat stress. The shortest

[24] The ThinkHazard! project was initiated in 2015 to facilitate greater access to hazard information and risk management guidance for development sector professionals. The open access thinkhazard.org website enables users to screen potential project locations for the existence of multiple natural hazards, then to obtain guidance on how to manage the risks to their project, and any impacts of their project on the local hazard.

return period is 5 years, which reflects more frequent extreme heat events. Based on the 30 years of available daily maximum WGBT data, longest return period that can be generated is 100-year return period. The following frequency classes are used in ThinkHazard! version 2: (i) high: 5-year return period, (ii) medium: 20-year return period and low: 100-year return period.

50. In 2014, AR5 Synthesis Report suggests that surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. Except for Latur, all the districts in Maharashtra will have high climate risk from extreme heat hazard level. At 32°C or above, these districts will have prolonged exposures to extreme heat and expected to occur at least once in the next five years.

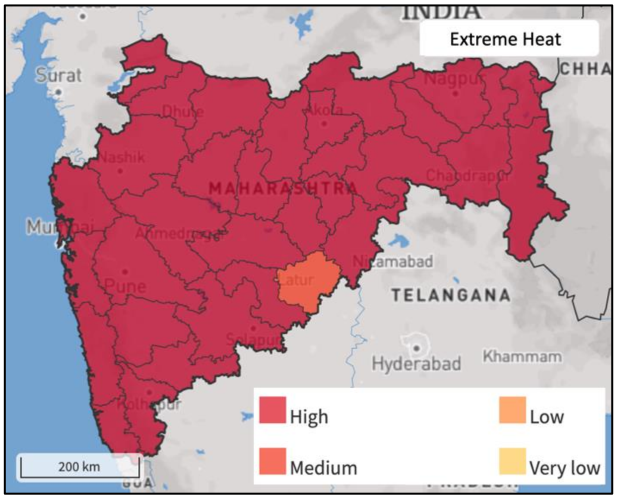


Figure 12. Affected areas by different level of heat waves hazards in Maharashtra

Flooding from Rivers

51. ThinkHazard! classified river flooding by using “area flooded to damaging intensity”. The damaging intensity threshold is 0.5 m and the area threshold is 1% of the admin unit. Indicating severity of a flood, the intensity of river flooding hazard is commonly expressed as the water depth at a specific location. The European joint research project RiskMap recommends four water depth classes: <0.5m, 5m.- 1m, 1m-2m and >2.0 m in determining a suitable intensity threshold. The web-based tool classified using frequency thresholds of 10, 50 and 1000 for high, medium and low hazard, respectively.

52. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. Recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (ARC5, 2014). At medium hazard level, there are 11 districts that will experience river flooding due to overflow of river channels from sustained or intense rainfall. These districts are Akola, Yavatmal, Nanded, Latur, Parbhani, Sangli, Nagpur, Chandrapur, Wardha, Bhandara and Gadchiroli. This means that there is a chance of more than 20% that potentially damaging and life-threatening river flooding that occur in the coming 10 years. Based on the tool, there are no high-level hazard from river flooding.

53. The districts of Amaravati, Washim, Buldhana, Osmanabad, Hingoli, Beed, Aurangabad, Jalna, Raigad, Palghar, Thane, Gondia, Ahmednagar, Nandurbar, Jalgaon and Nashik have low hazard levels. This means that there is a chance of more than 10% that potentially damaging and

life-threatening river floods occur in the coming 10 years. While Dhule, Sindhudurg and Ratnagiri has very low hazard level, which means there is a e <10% chance river floods occur in the coming 10 years. Figure 13 shows the distribution of different hazard levels in the state.

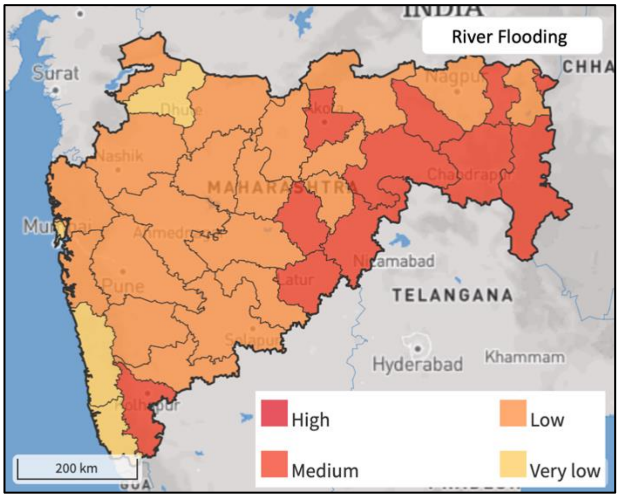


Figure 13. Affected areas by different levels of river flooding hazards in Maharashtra

Cyclone Events

54. A non-frontal storm system characterized by a low-pressure center, spiral rain bands and strong winds, cyclone events in Maharashtra originate over the Arabian sea and Bengal Bay. All of the districts at the western Maharashtra are classified at the high cyclone hazard level. Located at the eastern part of the state, the Gadchiroli District in Konkan Region is also considered at the high hazard level because of the cyclones coming from the Arabian Sea (Figure 14).

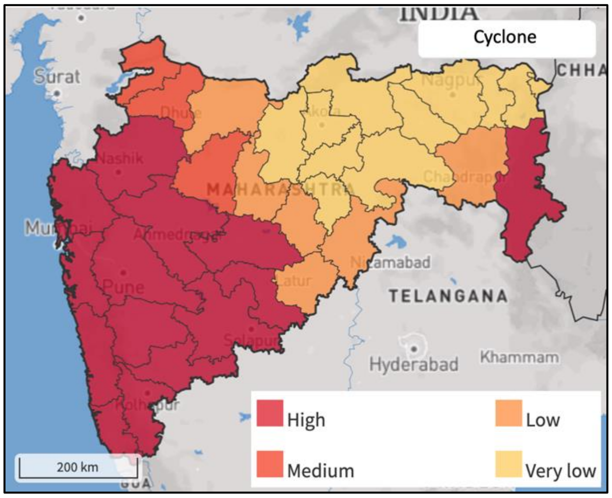


Figure 14. Affected areas by different levels of cyclone hazards in Maharashtra

55. Aside from the damages due to wind, cyclone can induce heavy rainfall and subsequent flooding. Aurangabad, Nandurbar and Dhule Districts has medium level of hazard, which describe

the expected frequency of damaging tropical cyclone winds. At this cyclone hazard level, there is a 10% chance of potentially-damaging wind speeds in these divisions in the next 10 years.

56. The (i) divisions of Nanded, Chandrapur, Parbhani, Jalna, Aurangabad and Jalgaon have low cyclone hazards and (ii) divisions of Nagpur, Wardha, Bhandara, Gondia Akola, Amaravati, Washim, Buldhana, Yavatmal and Hingoli is at very low cyclone hazard level because these places are located at the middle regions of the state (Figure 14). According to the ThinkHazard!, there will be 1% chance of potentially-damaging cyclone-strength winds to occur in the districts with low level hazard, while there will be >1% for the very low level within 10 years.

Coastal Flooding events

57. Increased elevation of coastal waters above usual sea levels or coastal flooding is caused combination of phenomena such as astronomical tide, storm surge during a storm or cyclone, and heightened wave set-up resulting from the energy transferred from offshore waves to the coastal zones. Based on intensity of the event and local topography, the web-based tool uses the extent of flooded area and the depth of floodwater. The ideal input to the analysis is onshore inundation depth maps or inundation depth at the coastline to process the hazard categorization procedure.

58. Eastern part of the state, where the Arabian Sea meets the Konkan Region, is at high hazard coastal flooding level. Naturally, these districts will experience increased flood depths due to combination of tides, cyclones and waves. The coastal flooding in the districts of Palghar, Ratnagiri and Thane is high level due to their locations (Figure 15). However, along the coastlines of Maharashtra, Sindhurug is at medium hazard level in terms of coastal flooding. The level of Sindhurug means that there is > 20% chance of potentially-damaging coastal flood waves occurring in the next 10 years.

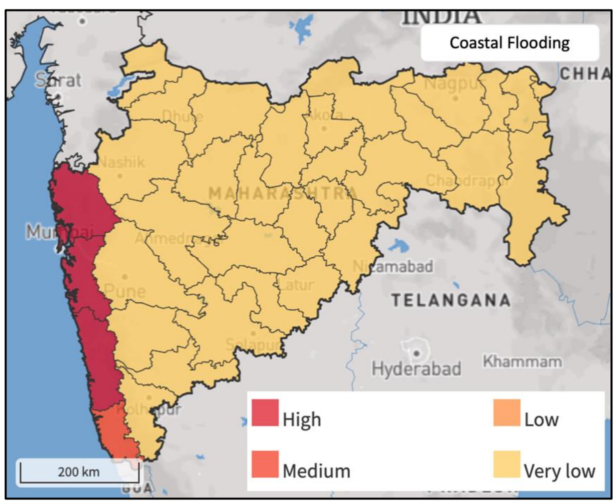


Figure 15. Affected areas by different levels of coastal flooding hazards in Maharashtra

Table 9. Summary of Climate Hazards and Risks according to the ThinkHazard! Tool.

Division	District	Temperature increase	River Flooding	Coastal Flooding	Cyclones

Amaravati	Akola	High	Medium	Very Low	Very Low
	Amaravati	High	Low	Very Low	Very Low
	Washim	High	Low	Very Low	Very Low
	Buldhana	High	Low	Very Low	Very Low
	Yavatmal	High	Medium	Very Low	Very Low
Aurangabad	Osmanabad	High	Low	Very Low	High
	Nanded	High	Medium	Very Low	Low
	Hingoli	High	Low	Very Low	Very Low
	Beed	High	Low	Very Low	High
	Latur	Medium	Medium	Very Low	Low
	Parbhani	High	Medium	Very Low	Low
	Aurangabad	High	Low	Very Low	Medium
	Jalna	High	Low	Very Low	Low
Konkan	Raigad	High	Low	Very Low	High
	Palghar	High	Low	High	High
	Sindhudurg	High	Very Low	Very Low	High
	Ratnagiri	High	Very Low	High	High
	Thane	High	Low	High	High
Nagpur	Nagpur	High	Medium	Very Low	Very Low
	Chandrapur	High	Medium	Very Low	Low
	Wardha	High	Medium	Very Low	Very Low
	Bhandara	High	Medium	Very Low	Very Low
	Gadchiroli	High	Medium	Very Low	High
	Gondia	High	Low	Very Low	Very Low
Nashik	Ahmednagar	High	Low	Very Low	High
	Nandurbar	High	Low	Very Low	Medium
	Dhule	High	Very Low	Very Low	Medium
	Jalgaon	High	Low	Very Low	Low
	Nashik	High	Low	Very Low	High
Pune	Satara	High	Low	Very Low	High
	Kolhapur	High	Low	Medium	High
	Sangli	High	Medium	Very Low	High
	Solapur	High	Low	Very Low	High
	Pune	High	Low	High	High

Vulnerability Assessment

Amravati

59. Amravati is located at the north-eastern part of Maharashtra state. This part of the state has a tropical wet and dry climate with hot-dry summers from the months of March to June. Monsoon season in Amravati starts from July until October, while warm winters from November to March. Under the Additional Financing, 150 rural roads are proposed to cover 385 kms and 33 bridges distributed in Akola, Amaravati, Washim, Buldhana and Yavatmal Districts.

60. Based on the temperature and rainfall projections of the regions (CMIP5 and RCP8.5), Amravati will have average monthly increase of (i) temperature at of .71°C and (ii) rainfall at 9.95 mm. The region is identified with high hazard levels on heat waves, which is generally predicted for the entire state. Based on projected climate hazards, there could be 150 rural roads and 33 bridges at risk to damage due to high temperature events. Only 2 districts are exposed to medium hazard level of river flooding that would put the 69 rural roads and 10 bridges to certain risks. Summary of these impacts is shown on the following table.

Table 10. Potential impacts of climate to the proposed Additional Financing in Amravati

Potential Climate Change Risks	Potential Impacts on Transport Infrastructure	No. of proposed rural roads at risk	No. of proposed bridges at risk
Increases in very hot days and heat waves	- Deterioration of pavement integrity, such as softening, traffic-related rutting, and migration of liquid asphalt - Thermal expansion of bridge expansion joints and paved surfaces	150	33
Increase in intense precipitation events	- Increase in scouring of roads, bridges, and support structures - Damage to road infrastructure due to landslides - Overloading of drainage systems - Deterioration of structural integrity of roads and bridges due to increase in soil moisture levels - Changes in precipitation and water levels will impact road foundations - Stronger or faster velocity of water flows will also impact bridge foundations.	69	10

Source: Climate-Proofing ADB Investments in the Transport Sector: Road Infrastructure Projects, October 2011.

Aurangabad

61. The proposed Additional Financing in Aurangabad has the most number of rural roads and bridges, and largest coverage among all the proposed project works of other regions. In Aurangabad, there are 305 rural roads, which stretches 824 kms, and 61 bridges in the districts of Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad, and Parbhani. Under the

Köppen climate classification, these districts have features of semi-arid climate, which the annual mean temperatures range from 17–33 °C. Most of the rainfall occurs in the monsoon season from June to September.

62. The district in Aurangabad will experience average monthly increase of (i) temperature at of .77°C and (ii) rainfall at 12.59 mm (CMIP5 and RCP8.5). This region is classified as high hazard level in terms of heat stress, except for Latur District which has lower hazard classification. Excluding the project components in Latur area, there will be 273 rural roads and 54 bridges exposed to extreme future heat waves of the state. On river flooding, 3 districts of Aurangabad are classified as medium hazard level, namely Nanded, Latur and Parbhani. The number of rural roads and bridges that could experience flooding is 106 and 27, respectively. Fortunately, the rest of the districts has low level of flooding hazards. For rural roads and bridges exposed to cyclone risks, the proposed project in the districts of Osmanabad and Beed would high possibility to experience damages due to cyclones. There could be 100 rural roads and 19 bridges that can be affected by future cyclones. To a lesser extent, proposed projects in the district of Aurangabad may also experience cyclone damages. In this district, there are 35 rural roads and 7 bridges. Summary of these impacts is shown on the following table.

Table 11. Potential impacts of climate to the proposed Additional Financing in Aurangabad

Potential Climate Change Risks	Potential Impacts on Transport Infrastructure	No. of proposed rural roads at risk	No. of proposed bridges at risk
Increases in very hot days and heat waves	- Deterioration of pavement integrity, such as softening, traffic-related rutting, and migration of liquid asphalt - Thermal expansion of bridge expansion joints and paved surfaces	305	61
Increase in intense precipitation events	- Increase in scouring of roads, bridges, and support structures - Damage to road infrastructure due to landslides - Overloading of drainage systems - Deterioration of structural integrity of roads and bridges due to increase in soil moisture levels - Changes in precipitation and water levels will impact road foundations. - Stronger or faster velocity of water flows will also impact bridge foundations.	106	27
Increase of storm intensity	- Damage to road infrastructure and increased probability of infrastructure failures - Increased threat to stability of bridge decks - Increased damage to signs, lighting fixtures, and supports - Extreme weather events such as stronger and/or more frequent	135	26

	storms will affect the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows. - Increased wind loads and storm strengths will impact long span bridges, especially suspension and cable-stayed bridges.		

Source: Climate-Proofing ADB Investments in the Transport Sector: Road Infrastructure Projects, October 2011.

Konkan

63. The Konkan Division occupies the entire western coasts of Maharashtra. Shown in Table 12, there are 128 rural roads that stretches to 310 kms proposed within 5 districts, which are Raigad, Palghar, Sindhudurg, Ratnagiri and Thane. Also, there are 18 bridges, which are proposed under the Additional Financing in Raigad, Palghar and Sindhudurg.

64. Generally, the climate of Kokan region is hot and humid. The Northern part of the region (Thane and Raigad) experiences high rainfall in excess of 3,000 mm/year, high humidity in rainy season and the temperatures range between 22–30 °C . On the southern part, precipitation is dictated by southwest monsoon from June to September. The temperatures range from 20-30 °C , which the month of May is the hottest month.

65. According to climate projections, Konkan will experience average monthly increase of (i) temperature at of .79°C and (ii) rainfall at 38.09 mm. This region is also classified as high hazard levels on heat waves and cyclones, which means 128 rural roads and 18 bridges will be affected by high temperature. Some of the districts of Konkan have high hazard level on coastal flooding such as Palghar, Ratnagiri and Thane. However, there is only 1 rural road located at the coastal area that has most likely to be affected by these climate hazards, which is the SH-178 to Kalvi Tembavali Road. These can lead rural roads and bridges vulnerable to climate related impacts. Summary of these impacts is shown on the following table.

Table 12. Potential impacts of climate to the proposed Additional Financing in Konkan

Potential Climate Change Risks	Potential Impacts on Transport Infrastructure	No. of proposed rural roads at risk	No. of proposed bridges at risk
Increases in very hot days and heat waves	- Deterioration of pavement integrity, such as softening, traffic-related rutting, and migration of liquid asphalt - Thermal expansion of bridge expansion joints and paved surfaces	128	18
Increase in intense precipitation events	- Increase in scouring of roads, bridges, and support structures - Damage to road infrastructure due to landslides - Overloading of drainage systems	128	18

	- Deterioration of structural integrity of roads and bridges due to increase in soil moisture levels - Changes in precipitation and water levels will impact road foundations. - Stronger or faster velocity of water flows will also impact bridge foundations. - Increased salinity levels will reduce the structural strength of pavements and lead to precipitated rusting of the reinforcement in concrete structures.		
Increase of storm intensity	- Damage to road infrastructure and increased probability of infrastructure failures - Increased threat to stability of bridge decks - Increased damage to signs, lighting fixtures, and supports - Extreme weather events such as stronger and/or more frequent storms will affect the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows. - Increased wind loads and storm strengths will impact long span bridges, especially suspension and cable-stayed bridges.	128	18

Source: Climate-Proofing ADB Investments in the Transport Sector: Road Infrastructure Projects, October 2011.

Nagpur

66. According to the projections of CMIP5 and RCP8.5, the districts in Nagpur will have average monthly increase of (i) temperature at of .68°C and (ii) rainfall at 13.79 mm based on RCP8.5. The heat wave hazard level is high for entire Nagpur Division, wherein 124 rural roads and 54 bridges at risk to high temperature damages (Table 13). For cyclone impacts, only the district of Gadchiroli will experience high probability to damages due to strong winds. There are only 2 rural roads and 2 bridges proposed in Gadchiroli, which could be affected in the future. On river flooding, majority of the districts of Nagpur are classified as medium hazard level, namely Nagpur, Chandrapur, Wardha, Bhandara, and Gadchiroli. The number of rural roads and bridges that could experience flooding is 90 and 42, respectively.

Table 13. Potential impacts of climate to the proposed Additional Financing in Nagpur

Potential Climate Change Risks	Potential Impacts on Transport Infrastructure	No. of proposed rural roads at risk	No. of proposed bridges at risk

Increases in very hot days and heat waves	- Deterioration of pavement integrity, such as softening, traffic-related rutting, and migration of liquid asphalt - Thermal expansion of bridge expansion joints and paved surfaces	124	54
Increase in intense precipitation events	- Increase in scouring of roads, bridges, and support structures - Damage to road infrastructure due to landslides - Overloading of drainage systems - Deterioration of structural integrity of roads and bridges due to increase in soil moisture levels - Changes in precipitation and water levels will impact road foundations - Stronger or faster velocity of water flows will also impact bridge foundations.	90	42
Increase of storm intensity	- Damage to road infrastructure and increased probability of infrastructure failures - Increased threat to stability of bridge decks - Increased damage to signs, lighting fixtures, and supports - Extreme weather events such as stronger and/or more frequent storms will affect the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows. - Increased wind loads and storm strengths will impact long span bridges, especially suspension and cable-stayed bridges.	2	2

Source: Climate-Proofing ADB Investments in the Transport Sector: Road Infrastructure Projects, October 2011

Nashik

67. According to the Köppen climate type, the division of Nashik is a hot semi-arid climate. The climate of the region tends to have hot (sometimes extremely hot) summers and warm to cool winters, with minimal precipitation. Based on climate projections (CMIP5 and RCP8.5), the region will experience monthly increase of temperature at of .79°C and monthly increase of rainfall at 9.67 mm.

68. The level of projected heat wave hazard in the entire region is high based on the ThinkHazard! anaylsis. This means there could be 175 rural roads (516 kms) and 55 bridges at risk to high temperatures (Table 14). Also, there are other districts in Nashik that are susceptible

to cyclones, which are Ahmednagar and Nashik districts. In these areas, there are proposed 105 rural roads and 15 bridges that could experience damages from cyclones. At a lesser possibility, there are proposed 37 rural roads and 20 bridges in Nandurbar and Dhule that could experience damages by strong winds and high rainfall due to cyclones. Summary of these impacts is shown on the following table.

Table 14. Potential impacts of climate to the proposed Additional Financing in Nashik

Potential Climate Change Risks	Potential Impacts on Transport Infrastructure	No. of proposed rural roads at risk	No. of proposed bridges at risk
Increases in very hot days and heat waves	- Deterioration of pavement integrity, such as softening, traffic-related rutting, and migration of liquid asphalt - Thermal expansion of bridge expansion joints and paved surfaces	175	55
Increase of storm intensity	- Damage to road infrastructure and increased probability of infrastructure failures - Increased threat to stability of bridge decks - Increased damage to signs, lighting fixtures, and supports - Extreme weather events such as stronger and/or more frequent storms will affect the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows. - Increased wind loads and storm strengths will impact long span bridges, especially suspension and cable-stayed bridges.	142	35

Source: Climate-Proofing ADB Investments in the Transport Sector: Road Infrastructure Projects, October 2011.

Pune

69. The Köppen Climate Classification subtype for Pune, Maharashtra is tropical savanna climate. Average temperature for the year in Pune is 23.9°C. April is the warmest month, with an average of 28.9°C. While, the coolest month on average is January, with an average 20°C. The average amount of precipitation for the year in Pune is 703.6 mm, wherein July is month with most average precipitation with 175.3 mm.

70. Based on climate change projections (CMIP5 and RCP8.5), the districts in Pune will experience average monthly increase of (i) temperature with of .78°C and (ii) rainfall with 10.61 mm. Similar to other divisions of the state, the region is classified as high hazard level in terms of heat waves. The proposed 219 rural roads and 15 bridges will be exposed to future high-temperature events of the state. All districts are also exposed to the tropical cyclonic wind speeds, which the proposed projects are at risk in this region. On river flooding, only district of Sangli is at risk of experiencing inundation damages with medium hazard level classification. The number of

rural roads and bridges that could experience flooding is 38 and 1, respectively. Kolhapur and Pune will have climate risks from coastal flooding, which the later has a higher level.

Table 15. Potential impacts of climate to the proposed Additional Financing in Pune

Potential Climate Change Risks	Potential Impacts on Transport Infrastructure	No. of proposed rural roads at risk	No. of proposed bridges at risk
Increases in very hot days and heat waves	- Deterioration of pavement integrity, such as softening, traffic-related rutting, and migration of liquid asphalt - Thermal expansion of bridge expansion joints and paved surfaces	305	61
Increase in intense precipitation events	- Increase in scouring of roads, bridges, and support structures - Damage to road infrastructure due to landslides - Overloading of drainage systems - Deterioration of structural integrity of roads and bridges due to increase in soil moisture levels - Changes in precipitation and water levels will impact road foundations. - Stronger or faster velocity of water flows will also impact bridge foundations. - Increased salinity levels will reduce the structural strength of pavements and lead to precipitated rusting of the reinforcement in concrete structures.	106	27
Increase of storm intensity	- Damage to road infrastructure and increased probability of infrastructure failures - Increased threat to stability of bridge decks - Increased damage to signs, lighting fixtures, and supports - Extreme weather events such as stronger and/or more frequent storms will affect the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows. - Increased wind loads and storm strengths will impact long span bridges, especially suspension and cable-stayed bridges.	135	26

Source: Climate-Proofing ADB Investments in the Transport Sector: Road Infrastructure Projects, October 2011.

V. CLIMATE ADAPTATION MEASURES

71. With the projected increase in rainfall and temperature due to climate, more frequent and intense climate events are anticipated in the state. The MRRDA has identified adaptation measures to increase resiliency of rural roads and bridge against future climate risks. The climate considerations and design features of the rural roads and bridges will be part of the DPRs to ensure that these bridges can safely and reliably provide essential access for communities. The cost of these adaptation measures is $78. 63 million. Climate adaptation measures and amount for rural roads and bridges are given in the following paragraphs.

Rural Roads

Cross Drainage

72. Based on projections, climate in Maharashtra will have increase rainfall and more frequent extreme precipitation events, which will increase the risk from floods and likely to damage the roads. Not enough cross drainage can increase the risk of flooding in the upstream and flood flow velocity downstream. To mitigate these impacts, adequate cross drain as per IRC: SP-20:2002 have to be provided. More specifically:

(i) Provision of adequate cross drainage structure will be made to ensure smooth passage of water and maintaining natural drainage pattern of the area.
(ii) Adequate drainage structures will be provided in water stagnant or logging areas.
(iii) Additional cross drainage structure will be designed in the areas where nearby land is sloping towards road alignment on both the sides.

Retaining Walls

73. As part of the rural road design, retaining wall structures will be built to provide lateral support to the soil mass and slopes to prevent them from sliding and eroding. As protection works, retaining walls will be constructed to strengthen the roads' embankment with reinforcement concrete. Of all the divisions, the region of Konkan has the most retaining walls because of the hilly characteristics of the project area.

Increase of embankments height

74. The flood levels higher than the road surface cause road damages by overtopping of water and scouring of the road pavements and embankments. High-water level can reduce the bearing capacity of the road. Coupled with proper cross drainage structure, Road surface higher than water level will provide an all-season road that will considerably reduce risks for damage of any part of the road.

75. Raising the road levels will involve new superstructure of the rural roads and additional embankment materials. The road superstructure normally consists of pavement, base course and sub-base course and the thickness of each layer depend on the design criteria, amount of traffic and the quality of underlying layers as per IRC SP 72 - 2015. MRRDA will use paving materials such as water based macadam to adapt with extreme heat conditions. Planting of trees along rural roads will help of reducing the temperature that rural roads would receive later on.

Side Drains

76. Surface run-off must not increase in terms of amount and flow velocity, which will cause excessive wear of the exposed road surfaces. The presence of excess water within the roadway will adversely affect the properties of the road materials. Inadequate or poorly-designed drainage will result to cut or fill failures, road surface erosion and weakened subgrades. To solve this, properly maintained road drainage system is vital for all type of roads. Good drainage system bears water from the surface of the road, as well from the different layers of the road structure, to a safe discharge such as stream or cross drainage structure. Through a controlled manner, drainage system catches rainfall run-off that would flow towards the road, thus, the damaging effect of water flow velocity is reduced. Considering the number of proposed rural roads, Aurangabad has the most side drains to construct of all the regions under the Additional Financing. The table below shows the climate adaptation financing for the rural roads.

Table 16. Amount of climate adaptation financing of rural roads for each region

Region	Cost of new cross drainage (Lakhs INR)	Cost of increase in cross drainage size (Lakhs INR)	Cost of new Retaining Wall (Lakhs INR)	Cost of increase in height of road embankment (Lakhs INR)	Cost of new side Drains (Lakhs INR)	Total Cost (Lakhs INR)	Total Cost in Million INR
Nashik	4637.42	1348.45	1001.35	458.21	21.88	7467.31	746.73
Nagpur	3529.41	1461.69	301.51	21.35	1199.7	6513.66	651.37
Pune	3253.15	1652.88	967.93	1762.49	630.67	8267.12	826.71
Konkan	1572.81	2470.82	1788.33	650.59	1224.4	7706.95	770.69
Amravati	4526.23	1023.51	569.22	0	350.14	6469.1	646.91
Aurangabad	5259	2369.63	845.85	73.8	390.15	8938.42	893.84
Total Cost	**22778.02**	**10326.97**	**5474.2**	**2966.43**	**3816.93**	**45362.55**	**4536.26**

Bridges

Approach Roads

77. The road surface level will be raised higher than expected flood level to reduce risk of damage and to minimize inaccessible bridge during inundation. The requirements for grading, embankment, sub-base will conform to Indian Road Congress. Also, it is crucial to use suitable construction materials that are more resistant to damage in extreme heat conditions. One factor that influences the amount of climate adaptation cost is the length of approach roads. In Akola District, the length of approach road for the Sangvi Jamdev Road at Ch- 1/500 reaches to 1,820 m. In general, the cost of the approach roads structure is 54% of the bridges' total climate adaptation financing.

Retaining Wall

78. Wall structures are included in abutments, which is connected to the embankment. Retaining or wing walls are short structures to prevent erosion and add stability to the bridge. Their main function is to retain the approach roadway embankment against river flow or high flood velocity during extreme climate events. Both new bridges and for upgrading will have retaining walls, but for the selected bridges that need this kind of structure.

Embankment protection

79. For both new bridges and to be upgraded, the sloping surface of the embankments has to withstand erosive action of river flow. Surface protection of embankments are used to reduce rainwater infiltration and to prevent erosion of materials. One way to protect the bridges under the additional financing is by means of stone pitching – lay stone rubble (with filter layer underneath) onto surface to protect slope from weathering of high rainfall and temperature.

Aprons

80. MRRDA has considered aprons as part of the bridges' design to protect the riverbed against scouring effect of river flow, especially during heavy rainfall and flooding. The protective structural measures at the base of a bridge will improve the climate resiliency of the bridges such as those located at Nagpur and Konkan Divisions. These areas are expected to have more frequent flooding and cyclones that could cause damage at the base of the bridges. The cost of the climate adaptation financing of the bridges is shown in the table below.

Table 17. Amount of climate adaptation financing of bridges for each region.

Region	No. of new bridges	New bridges' climate adaptation cost (Lakhs INR)	No. of upgradation bridges	Upgradation bridges' climate adaptation cost (Lakhs INR)	Total Climate Adaptation (Lakhs INR)	Total Cost in Million (INR)
Nashik	51	2731.63	4	203.04	2934.67	293.47
Nagpur	38	2566.28	16	987.1	3553.37	355.34
Pune	11	855.58	4	329.09	1184.67	118.47
Konkan	4	896.06	14	528.05	1424.11	142.41
Amravati	23	1307.85	10	503.05	1810.9	181.09
Aurangabad	43	2626.35	18	1010.2	3636.55	363.66
Total Cost	**170**	**10983.74**	**66**	**3560.54**	**14544.28**	**1454.43**

81. Similar to the current project, the Additional Financing will invest on the climate resiliency of the rural roads and bridges by increasing the capacity of cross drains and creating new ones, building retaining walls, increasing the road elevation and providing aprons to bridges. The summary of climate adaptation cost of the Additional Financing is shown on the table below.

Table 18. Amount of climate adaptation financing for each region.

Region	Rural Roads (USD)	Bridges (USD)	Total per Region (USD)
Nashik	9,802,179	3,852,323	*13,654,502*
Nagpur	8,550,407	4,664,479	*13,214,886*
Pune	10,852,061	1,555,133	*12,407,194*
Konkan	10,116,697	1,869,388	*11,986,085*
Amravati	8,491,861	2,377,133	*10,868,994*

Aurangabad	11,733,263	4,773,694	*16,506,957*
Total Cost	**59,546,469**	**19,092,150**	**78,638,619**

82. Through the ongoing RCIP, the project will initiate the capacity building of MRRDA in climate screening, decision support systems to include knowledge products on climate resilient technologies and practices, design of information support systems to analyze climate data, and post-disaster risk and recovery among others.

VI. CLIMATE MITIGATION

83. Using the ADB's Transport Emissions Evaluation Model for Projects (TEEMP), the improvement in road surface will allow vehicle to travel at optimum speed which results to lower fuel consumption and lower carbon dioxide emissions. For the entire economic project life of 20 years, carbon dioxide emission reduction from road roughness improvement is estimated at 58,372 tons. Annex 1 shows the procedure on computing GHG emissions from vehicles under the additional financing scenario.

Table 19. Amount of climate mitigation financing for each region.

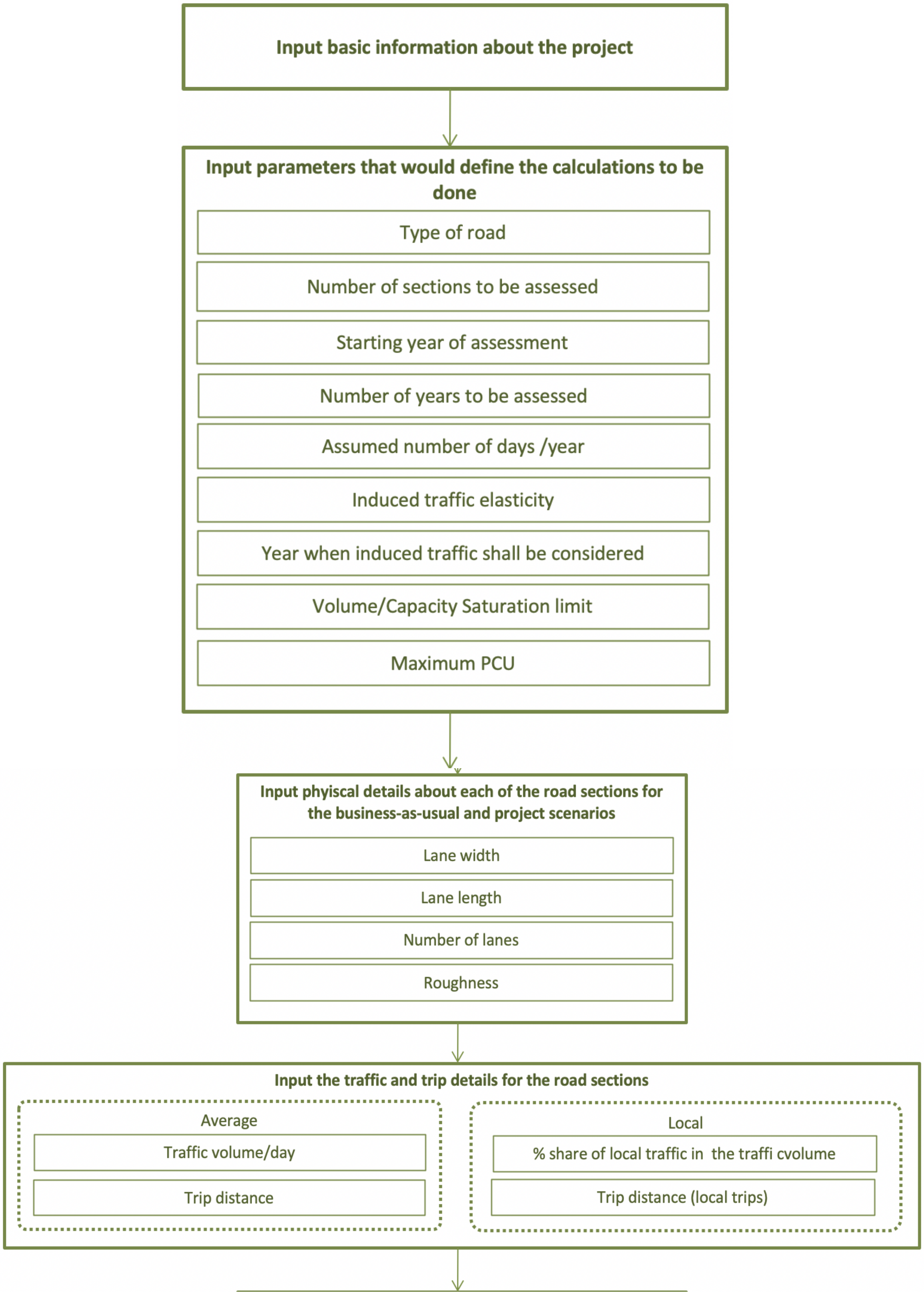
Mitigation Activity	**Estimated GHG Emissions Reduction** (tCO_2e/year)[a]	**Estimated Mitigation Costs** ($ million)	**Mitigation Finance Justification**
Improvements in the condition of road surfaces and improvements to regular operation and maintenance of upgraded roads.	2,919	18.01 (estimated at 4.7% of the construction which cost accounts for the road carpeting)	The project's main objective is to improve connectivity between rural habitations, productive agricultural lands and economic growth centers across the state. In doing so, the project will also improve the surface condition of rural roads. This allows road users to travel at faster speeds and avoid congestions. The net effect will be a reduction in fuel consumption by vehicles.

GHG = greenhouse gas; tCO_2e = tons of carbon dioxide equivalent.
[a] Energy savings/year x emission factor = GHG emissions reduction.

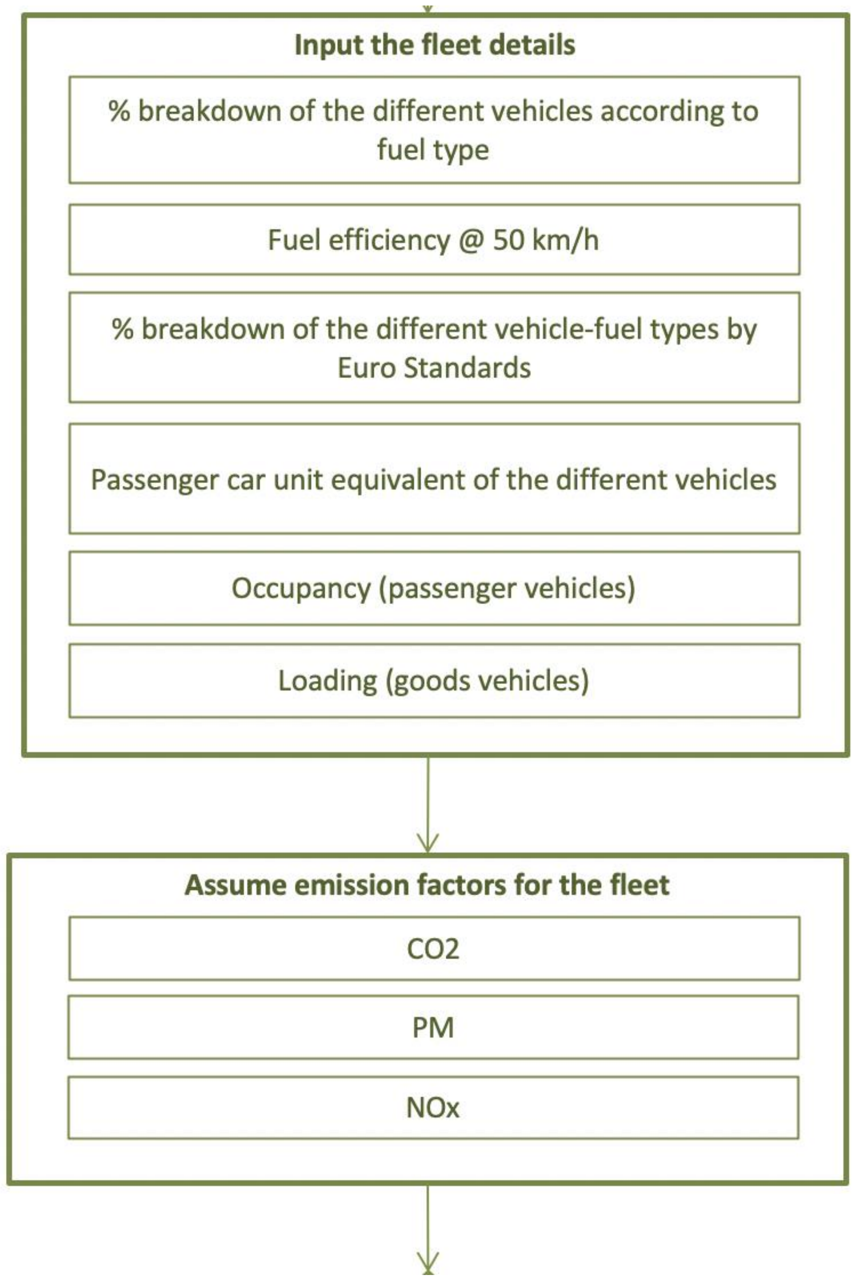
84. The roads and bridges will be covered under contractual maintenance for 5 years after the date of construction.[25] The manuals for the road maintenance, climate-resilient designs and rural road construction will also be developed under the project. The cost of the 5-year maintenance is estimated at INR ₹13,170.10 (lakh).

Annex 1. Steps on computing the GHG emission for RCIP-AF using TEEMP.

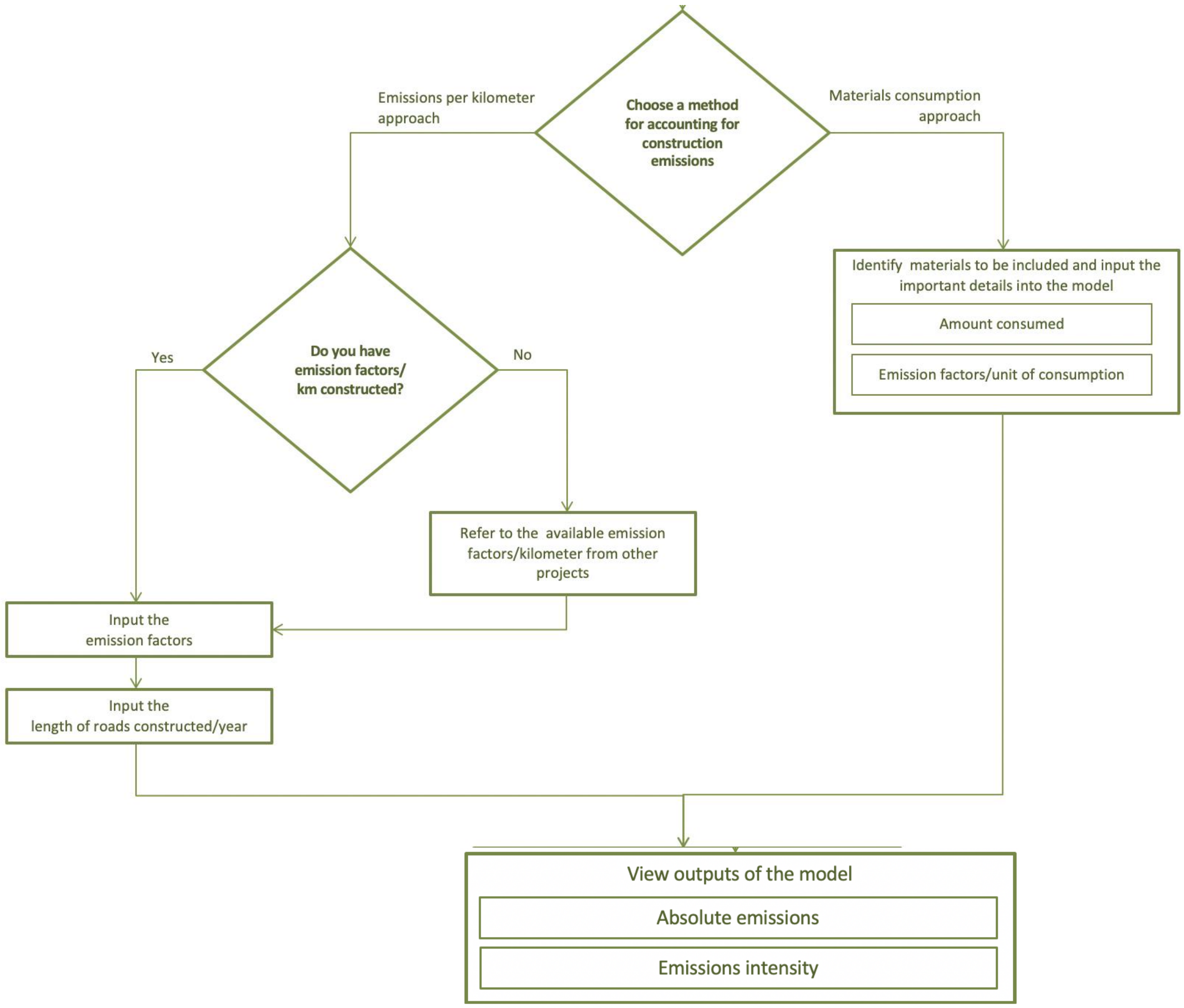
[25] Routine maintenance will be undertaken for 5 years by the same contractors that built the roads. All maintenance will be financed by the government.



Input the fleet details… (flow continued on the next page)



Choose a method for accounting for cosntruction emissions
(flow continued on the next page)


Choose a method for accounting for construction emissions
Emissions per kilometer approach
Materials consumption approach
Do you have emission factors/ km constructed?
Yes
No
Identify materials to be included and input the important details into the model
Amount consumed
Emission factors/unit of consumption
Refer to the available emission factors/kilometer from other projects
Input the emission factors
Input the length of roads constructed/year
View outputs of the model
Absolute emissions
Emissions intensity