CLIMATE CHANGE ASSESSMENT

I. BASIC PROJECT INFORMATION

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Maharashtra State Road Improvement Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Cost</td>
<td>$177.00 million</td>
</tr>
<tr>
<td>Location</td>
<td>Maharashtra</td>
</tr>
<tr>
<td>Subsector</td>
<td>Transport (Road Transport [Nonurban])</td>
</tr>
<tr>
<td>Theme</td>
<td>Inclusive economic growth; Environmentally sustainable growth</td>
</tr>
</tbody>
</table>

**Brief Description:**
The scope of works under the Maharashtra State Road Improvement Project involves the widening and upgrading of 13 existing rural state highways and major district roads to two-lane width. These roads are grouped into nine contracts under the engineering, procurement, and construction model for about 450 kilometers (km) of state roads forming part of the core road network. Expansion is within the available right of way, which is generally 24–30 meters with reduced width in built-up sections. Majority of the roads are intermediate lane with or without shoulder.

Terrain is mostly rolling except in a few ghat sections characterized by hilly profile. Abutting land use is predominantly open-agricultural. Pavement conditions are generally poor to fair. Roadside drains are present in some urban stretches but mostly choked and non-functional. Overtopping of roads is not observed but waterlogging is very common in built-up areas.

The project roads are widely scattered in various districts with various physiographic and climatic variations. The area west of the Ghat mountains (Konkan lowlands) receives heavy monsoon rains. Just 150 km to the east are drought-prone areas where long dry spells are common. The far eastern zones are characterized by moderate to high rainfall patterns. The average annual rainfall in the state is 1,181 millimeters (mm), 75% of which is received during the southwest monsoon in June to September. The state is also prone to various natural disasters such as heat waves, droughts, floods, cyclones, and earthquakes.

II. SUMMARY OF CLIMATE CHANGE FINANCE

<table>
<thead>
<tr>
<th>Project Financing</th>
<th>Amount ($ million)</th>
<th>Adaptation ($ million)</th>
<th>Mitigation ($ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian Development Bank</td>
<td>177.00</td>
<td>12.76</td>
<td>0.00</td>
</tr>
</tbody>
</table>


III. SUMMARY OF CLIMATE RISK SCREENING AND ASSESSMENT

A. Sensitivity of Project Components to Climate or Weather Conditions and Sea Level

1. **Small and/or minor bridges, culverts, and drains.** Flow volumes from projected extreme rainfall events may exceed capacity and cause damage to drainage structures.
2. **Road embankment.** Excess flows may lead to water-logging and flooding in low lying, critical portions of the project roads, which may lead to pavement damage (e.g., scouring, potholes, etc.).
3. **Road pavement.** Increase in temperature can cause softening, rutting, and cracking of road pavement.

B. Climate Risk Screening

The state of Maharashtra has diverse ecosystems with their inherent assortments of risks under climatic as well as nonclimatic exposures and with differential vulnerability profiles. It is prone to various natural hazards such as heat waves, droughts, floods, cyclones, and earthquakes. Historical data shows a generally increasing trend in mean maximum temperature and decreasing rainfall trends. However, climate projections using PRECIS model for SRES A1B scenario and CNRM-CM5 projected a
decreasing trend of rainfall under RCP 4.5 scenario and decrease in rainfall in the early century and increasing trend for the mid- and end-centuries under RCP 8.5 scenario.

1. **Exposure to extreme precipitation.** Heat waves in Maharashtra occur sporadically in various interior regions, thus impacting the structural integrity of the exposed road pavements. High temperatures and heat waves impact road pavement integrity, causing road surface failures by softening, and traffic-related rutting and cracking. It is also recognized that oxidation and the action of UV radiation cause excessive hardening of the asphalt close to the pavement surface and the material to become brittle over time. Hotter weather will speed up oxidation process and make the material more vulnerable to cracking. Cooler diurnal temperatures will generate thermal tensile stresses that cause crack initiation and propagation.

2. **Extreme rainfall.** Temperature and rainfall are projected to increase all over the state with some regional variations. Amravati division (Vidarbh region) and Aurangabad division (Marathwada region) are forecast to experience greater rise in annual mean temperatures than other parts of the state. This will lead to intense rainfall events with longer dry or low rainfall spells in between. Extreme rainfall is projected to increase in all regions of the state with greater increases in the northern regions.

3. **Flooding.** Extreme rainfall in future decades is projected to increase in all regions of the state with greater increases in the northern parts. This will lead to heavy flooding, which will definitely impact the state’s road infrastructure. This problem is particularly acute on roads in urban areas owing to the high proportion of impermeable surfaces that prevent infiltration of water into the soil. This results in uncontrollable overland flow that causes drains to exceed their capacity, and also increases the likelihood of drain blockages. As defined by the IMD, a rainfall over 244.5 mm in 24 hours is considered “extremely heavy rainfall.” Such intense rainfalls are the main cause of urban floods and flash floods that impact hill slopes, resulting in landslides and overwhelming the channel equilibrium of roadside drainages. The districts of Akola, Amravati, Ratnagiri, Solapur, and Yavatmal have recorded rainfall of over 124.4 mm in 24 hours, which is the IMD’s threshold for “very heavy rain.”

4. **Cyclones.** The coastal district of Ratnagiri is classified high for cyclone hazards. This means that there is more than 20% chance of potentially damaging wind speeds in the project area in the next 10 years. It must be noted that damages occur not only due to high velocity winds but also to heavy rainfall and subsequent flooding, which include coastal floods.

**Climate Risk Classification:** medium

**C. Climate Risk and Adaptation Assessment**

1. The CRVA was conducted through thorough review of available resources on the project state’s climate, both present and projected changes, climate change studies, and project documents, as well as consultations with stakeholders and experts. The report confirmed the initial climate risk classification as medium. The CRVA is provided as an appendix of this assessment.

2. Available information point to increase in temperature and rainfall, especially extreme rainfall events in the state. This necessitates design modifications of drainage structures including bridges and raised embankment height, and bitumen upgrade. The design has already adopted VG-30 grade instead of 60–70 penetration grade bitumen to address increasing temperatures in the state and in compliance with existing codes and standards.

**D. Climate Risk Screening Tool and/or Procedure Used**

ADB South Asia Department’s climate risk screening framework and methodology, full climate risk and vulnerability assessment, and ThinkHazard.b

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ADB= Asian Development Bank, CNRM-CM5 = Centre National de Recherches Meteorologiques Coupled Global Climate Model, version 5, CRVA = climate risk and vulnerability assessment, IMD= India Meteorological Department, mm = millimeter, PRECIS = Providing Regional Climates for Impacts Studies, RCP = representative concentration pathway, SRES = Special Report on Emissions Scenarios, UV = ultraviolet, VG = viscosity grade.


## IV. CLIMATE ADAPTATION PLANS WITHIN THE PROJECT

<table>
<thead>
<tr>
<th>Adaptation Activity</th>
<th>Target Climate Risk</th>
<th>Estimated Adaptation Costs ($ million)</th>
<th>Adaptation Finance Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase in design capacity of drainage structures (i.e., cross drainages of Ø900 mm hume pipes to be replaced by Ø1200 mm; and depending on the location and vulnerability, hume pipes to be replaced by box-type culverts, and some others replaced by larger capacity culverts)</td>
<td>Increased and/or extreme rainfall events</td>
<td>9.81</td>
<td>Designs include improvement of drainage structure sizes to cope with higher flooding frequency and magnitude based on updated hydrological assessments. Initial assessment of the existing roads has noted cross-drainages are inadequate to deal with projected flood discharges considering climate change. Even roads located in generally arid districts have been included in consideration of the changing climate.</td>
</tr>
<tr>
<td>2. Improvement in flood discharge capacities of small and minor bridges</td>
<td>Increased and/or extreme rainfall events</td>
<td>2.07</td>
<td>Design includes increase in vertical clearances of small and minor bridges considering projected increase in rainfall and extreme rainfall events</td>
</tr>
<tr>
<td>3. Improvements in vertical embankment heights in critical sections of project roads</td>
<td>Increased and/or extreme rainfall events</td>
<td>4.91</td>
<td>As a result of upgrading of sub-grade, sub-base and pavement thicknesses, the project roads will generally be raised by approximately 0.3 m throughout the entire stretch. However, the road inventory has identified a total of 23.5 km of critical areas requiring building up of embankments to overland flood-safe levels.</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>16.79</strong></td>
<td></td>
</tr>
</tbody>
</table>

ADB is financing 76% of the civil works cost of the project. Hence, of the total project adaptation cost of $16.79 million, ADB will finance about $12.76 million.

ADB = Asian Development Bank, km = kilometer, m = meter, mm = millimeter.

V. CLIMATE MITIGATION PLANS WITHIN THE PROJECT

<table>
<thead>
<tr>
<th>Mitigation Activity</th>
<th>Estimated GHG Emissions Reduction (tCO₂e)/year</th>
<th>Estimated Mitigation Cost ($ million)</th>
<th>Mitigation Finance Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

GHG = greenhouse gas, tCO₂e = tons of carbon dioxide equivalent, N/A = not applicable. Source: Asian Development Bank.
November 2019

IND: Maharashtra State Road Improvement Project

Prepared by the Public Works Department, Government of Maharashtra for the Asian Development Bank.
<table>
<thead>
<tr>
<th>ABBREVIATIONS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADB</td>
<td>Asian Development Bank</td>
</tr>
<tr>
<td>C</td>
<td>centigrade</td>
</tr>
<tr>
<td>CC</td>
<td>climate change</td>
</tr>
<tr>
<td>CMIP</td>
<td>Climate Model Intercomparison Project</td>
</tr>
<tr>
<td>CRVA</td>
<td>climate risk and vulnerability assessment</td>
</tr>
<tr>
<td>DPR</td>
<td>detailed project report</td>
</tr>
<tr>
<td>EPC</td>
<td>engineering, procurement, and construction</td>
</tr>
<tr>
<td>IEE</td>
<td>initial environmental examination</td>
</tr>
<tr>
<td>IMD</td>
<td>India Meteorological Department</td>
</tr>
<tr>
<td>INR</td>
<td>Indian rupee</td>
</tr>
<tr>
<td>IPC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IPCC</td>
<td>interim payment certificate</td>
</tr>
<tr>
<td>IRC</td>
<td>Indian Roads Congress</td>
</tr>
<tr>
<td>ISMR</td>
<td>Indian summer monsoon rainfall</td>
</tr>
<tr>
<td>km</td>
<td>kilometer</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>MDR</td>
<td>major district road</td>
</tr>
<tr>
<td>mm</td>
<td>millimeter</td>
</tr>
<tr>
<td>MPWD</td>
<td>Maharashtra Public Works Department</td>
</tr>
<tr>
<td>MSRIP</td>
<td>Maharashtra State Road Improvement Project</td>
</tr>
<tr>
<td>RCP</td>
<td>Representative Concentration Pathway</td>
</tr>
</tbody>
</table>

I. INTRODUCTION

A. Background

1. Maharashtra is the second largest state in India and encompasses a total land area of around 307,713 square kilometers. The state is divided into six administrative divisions that are further divided into 36 districts. Because the state is spread over a wide geographical area, it exhibits diverse climatic conditions governed by its varied geography, topography, and monsoonal rainfall influences. Located in the low latitudes (15.5°N–22°N), the state has a tropical monsoon climate with hot, rainy, and cool weather seasons. March, April, and May are the hottest months where the average maximum temperature varies between 30°C and 40°C. Some occasional thunderstorms occur over the state during this season. Monsoon rainfall starts normally in the first week of June while July is the wettest month. August too gets substantial rain until the monsoon retreats around September. Cool dry spells with clear skies, gentle breeze, and pleasant weather prevail from November to February. Temperature varies between 12°C and 35°C during this season.

2. Road transport infrastructures in Maharashtra are maintained by a myriad of organizations. The national highways running through the state are managed by the central government, the state highways and major district roads by the Maharashtra Public Works Department (MPWD), urban roads by the respective municipal entities, rural roads by local governments called zilla parishad and panchayat, and so on.

3. State highways together with major district roads are arterial routes of the state, linking district headquarters and important towns, and connecting them further with national highways and/or state highways of neighboring states. As of 31 March 2016, the state of Maharashtra accounted for the largest share in the total length of state highways in the country, with about 39,000 kilometers (km) or 22.14% of the entire nation’s total state highways.1

4. The Government of Maharashtra has applied for a loan from the Asian Development Bank (ADB) under the Maharashtra State Road Improvement Project (MSRIP) directed at upgrading state highways and major district roads under engineering procurement and construction (EPC) contracts. The MPWD is the executing agency for the MSRIP.

5. Works in selected roads will entail widening to two-lane width with paved shoulders, strengthening and reconstruction of road and drainage structures, and improvement of road and junction geometries to enhance road transport efficiency and road safety. Table 1 lists 13 MSRIP project roads with lengths varying from 10 km to 65 km, grouped into nine EPC packages.

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Table 1: MSRIP Project Roads

<table>
<thead>
<tr>
<th>#</th>
<th>Package #</th>
<th>MRIP Road Names</th>
<th>Length in km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EPC 1</td>
<td>Improvement of NH-66 to Kante Tulshi Devrukh Marleshwar Kalakdara (with Marleshwar Branch) Road SH174</td>
<td>23.50</td>
</tr>
<tr>
<td>2</td>
<td>(a)</td>
<td>Improvement to Chafe Ganpatipule road MDR-55</td>
<td>10.35</td>
</tr>
<tr>
<td>3</td>
<td>(b)</td>
<td>Improvement of Dahhole Shiposhi Korle Vatli Road joining to NH -17; SH-175</td>
<td>28.10</td>
</tr>
<tr>
<td>4</td>
<td>(a)</td>
<td>Improvement of Hatwale Jaitapur Road SH-170</td>
<td>23.70</td>
</tr>
<tr>
<td>5</td>
<td>EPC 3</td>
<td>Improvement of Barshi Sholapur Akalkot Dudhni Alanad to State border Road SH204 (Part Barshi to Solapur SH204)</td>
<td>61.90</td>
</tr>
<tr>
<td>6</td>
<td>EPC 4</td>
<td>Improvement of Daund Karmala Paranda Barshi Osmanabad Road SH68</td>
<td>50.54</td>
</tr>
<tr>
<td>7</td>
<td>EPC 5</td>
<td>Improvement to Shiraramp Vajapur Road Washim-Pushad Fursavangi Mandri Road (section Washim-Pushad) in Washim &amp; Yavatmal District SH-51</td>
<td>56.05</td>
</tr>
<tr>
<td>8</td>
<td>EPC 6</td>
<td>Improvement to Riddharpur Teosa Kurha Anjansingi Dhamangaon Rly Devgaon Babhugaon Road SH-300 (km 40/600 to 106/00) and Dhamangaon Bypass Road ( km 0/00 to 5/400) TQ, Teosa District Amravati &amp; Yavatmal</td>
<td>64.66</td>
</tr>
<tr>
<td>9</td>
<td>EPC 7</td>
<td>Improvement of Daryapur Akot SH47 Road ( Daryapur to Akot) District Amravati &amp; Akola, District Amravati &amp; Akola</td>
<td>24.00</td>
</tr>
<tr>
<td>10</td>
<td>(a)</td>
<td>Improvement of Daryapur Amla Runmochan Asara Road (section Daryapur to Asara) District MDR-21</td>
<td>17.55</td>
</tr>
<tr>
<td>11</td>
<td>EPC 8</td>
<td>Improvement Amravati Chandur Rly Talegaon Road SH297</td>
<td>15.08</td>
</tr>
<tr>
<td>12</td>
<td>(a)</td>
<td>Improvement to Riddharpur Lekhigaon Ner Pimpal Teosa Road SH300</td>
<td>40.80</td>
</tr>
<tr>
<td>13</td>
<td>(b)</td>
<td>Improvement to Daund Karmala Paranda Barshi Osmanabad Road SH66</td>
<td>35.23</td>
</tr>
</tbody>
</table>

TOTAL 451.46

EPC = engineering, procurement, and construction, km = kilometer, MDR = major district road, MSRIP = Maharashtra State Road Improvement Project, NH = national highway, SH = state highway.

Source: Maharashtra Public Works Department

B. Climate Change Policy of Maharashtra

6. The Government of Maharashtra had long aimed to mainstream climate action into development but lacked the institutional mechanisms, technical frameworks, and scientific data and capacity analysis to do so. Following a directive from the central government, the Government of Maharashtra commissioned a research institute in 2010 to draft a state action plan on climate change. The Department of Environment of Maharashtra and Action on Climate Today (ACT) program drafted a state climate change policy, which was approved by the State Cabinet in 2001. The policy presented a framework for each sector to initiate climate change mainstreaming into their plans and budgets.

7. The state government has approved new institutional structures for managing climate change: (i) the high-level Steering Committee on Climate Change to provide overall strategic guidance, and (ii) the Climate Change Cell within the Environment Department to coordinate and lead the day-to-day work. The line departments have developed sectoral climate action plans to implement the policy. While the state climate change policy had broad strategies for major economic sectors, it lacked sufficient guidance on implementation and thus could not be fully adopted to achieve its purpose. Maharashtra needed a more detailed plan with concrete measures for delivery.

8. The document, Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra (MSAPCC 2018), discusses the impact of climate change on six sectors—(i) agriculture, (ii) water resources, (iii) health, (iv) forests and biodiversity, (v) livelihoods, and (vi)
energy and infrastructure.\textsuperscript{3} It also projections for rainfall and temperature in the state, assesses future sea level rise, and discusses extreme rainfall, flooding, and adaptation in the Mumbai Metropolitan Region.

II. CLIMATE CHANGE RISK AND VULNERABILITY

A. Sector Climate Risk and Vulnerability

9. Scientific evidence shows that global average temperatures continue to increase. As a result, seas and oceans are warming, polar ice caps and high elevation glaciers in mountainous regions are melting, sea levels are rising, and there are more varied and extreme weather patterns. Under a changed future climate, there will be more incidents of record hot weather, precipitation levels and flooding risks will be higher and more frequent, and extreme weather events are projected to increase in frequency and severity.

10. There is a wealth of reports and studies done by government organizations, international agencies, and research faculties on the impacts of climate change on road infrastructure integrity and performance. Some of these provide recommendations in terms of adaptation measures. Two major types of climate-related risks to road infrastructure are (i) risks driven by long-term changes in temperature and precipitation, and (ii) impacts driven by changing weather conditions. Both could accelerate road infrastructure deterioration and increase severe damages and risks, causing traffic interruption and accidents, and, thereby, ultimately affecting economic activities.

11. Climate vulnerability has been traditionally understood in terms of a relationship between exposure, sensitivity, and adaptive capacity. Climate change vulnerability levels are influenced by variables such as geographic location, the local environment, and the ability of local authorities to respond to events and to adapt their assets in advance. Due to direct exposure to forces of nature, road infrastructure and operations are vulnerable to different types of weather conditions. These forces of nature are highly likely to be exacerbated under climate change, and the risks posed by extreme events such as flash floods, landslides, and deterioration of road pavements are amply imminent. Thus, it is imperative to be aware of the risks posed by increasingly frequent and intensified extreme weather events at the onset of road improvement design.

12. Generic impacts of climate change on road infrastructures and assets as reckoned in numerous literature are briefly outlined here. These impacts call for a reevaluation of the road design, construction, and maintenance process in order to achieve lasting benefits.

(i) Changes in rainfall, temperature, and evaporation patterns can alter the moisture balances in the road pavement foundation.

(ii) Rise in the water table can lead to the reduction of the structural strength of the road pavement, leading to damages to earthworks, embankments, and drainage systems.

(iii) Rise in air temperature and temperature extremes can accelerate the ageing of road surfacing bitumen layers, leading to surface cracking, migration of asphalt and rutting, and increased rate of wear and tear.

(iv) Rise in temperature extremes impacts on concrete construction practices, including thermal expansion of bridge expansion joints.

(v) Increases in precipitation and increase in intense precipitation events can cause overloading of drainage systems, causing backups and flooding, and increases in road wash-outs.

(vi) Changes in seasonal precipitation and river flow patterns induce increased risk of floods from runoff, landslides, slope failures, and damage to roads and bridges.

13. Storms and more frequent strong cyclones can bring about increased road flooding, greater probability of infrastructure failures, erosion of road base and bridge supports, bridge scour (removal of streambed material caused by swiftly moving water from around bridge abutments or piers), reduced clearance under bridges, and wind damage to signs, lighting, overhead cables, road signals, and tall structures.

B. Climate Risk and Vulnerability Assessment: The Rationale

14. It is universally recognized that climate change in the long run might produce new kinds of hazards and threats to infrastructure. Therefore, tackling climate change impacts involves strengthening and/or improving upon the already known deficiencies. Since 2010, ADB has defined its priorities for action that include assisting developing member countries in climate-proofing of projects to ensure their outcomes are not compromised by climate change and variability or by natural hazards in general.

15. ADB recognizes that development is about lasting benefits. Hence, climate risk and vulnerability assessment (CRVA) is done during the project preparation phase to examine climate change events and risks, and the technical and economic feasibility of adaptation measures are examined, where appropriate. A climate risk management approach is adopted by ADB in its investment projects. Based on the level of climate change risks for the project and the adaptation measures incorporated in the project design, the associated climate change adaptation costs are determined. In essence, the CRVA is a collaborative process aimed at informing project teams and stakeholders about future climate risks that can affect the performance of an investment project.

16. ADB has also institutionalized a framework in response to the mandate that exposure and vulnerability to climate change risks be identified and accounted for in the preparation of investment projects. The framework encourages a sequential process to assess climate change vulnerability and impacts, and to identify adaptation needs and options. The various terminologies used in vulnerability assessments are defined and presented in Appendix 1 of this report.

C. Scope, Methodology, and Limitations

1. Scope

17. The broad objectives of the CRVA are (i) to assess the exposure, sensitivity, and adaptive capacity of the project roads to climate risks, and (ii) to examine climate-risk adaptive interventions to build resilience. The scope of this report thus lies in the assessment of climate-related natural hazards and associated risks and the vulnerabilities of the MSRIP project roads. This report will be in part a brief narrative description with regard to the first objective cited above. However, the main focus of this CRVA is the second objective, which is to narrow down the deliberations to climate change adaptive measures envisaged for the project roads as reflected in the final detailed project reports (DPR) and to disclose their associated incremental costs.

2. Methodology

18. **Desk reviews.** It is prudent to approach the CRVA starting with desk reviews to explore the extent to which many of the questions in vulnerability assessment and adaptation have been previously explored. A number of resources are available online on climate change studies undertaken by various research institutes and government and nongovernment agencies. This report draws upon previous studies through literature search of materials that analyze the possible climate change impacts for investment projects in the transport sector. The DPRs for each of the project road as finalized in July 2019 were reviewed for this CRVA report. The DPRs are available upon request from the project team.

19. **Consultations with stakeholders and experts.** Broad-based consultation helps ensure a wide range of perspectives on climate change and vulnerabilities. The stakeholders usually possess first-hand knowledge about the extent to which climate stressors have affected or can affect the project. Experts can provide substantive information and analysis for vulnerabilities while engineers will be able to provide information or analysis related to sensitivities, including design and construction standards relevant to climate impacts, and adaptive capacity information.

3. Limitations

20. Due to the complexity and uncertainty of the factors that define climate risks and vulnerabilities, particularly at a project scale, climate proofing can be a challenging activity. Being a relatively young field of study, there are gaps in the guidance materials and information resources currently available to facilitate the climate proofing of investment projects within the region.  

21. As climate factors manifest their effects in a multitude of ways, there will certainly be a large number of important qualification and limitation issues in relation to the presentation of this vulnerability assessment and the application of adaptation strategies. It must be noted that at present, there is no clear and universally adopted methodology to model the adverse effects of climate change and its integration in infrastructure design.

22. Inevitably, some of the constraints in this CRVA report are from the author’s proposed methodology that could have impacted or influenced the application or interpretation of the information available in the reference materials pertaining to the project.

D. Data Inventory and Collection

23. The desk review as noted earlier can help unfold a wide variety of useful theoretical and methodological information and data. It includes the following sources:

   (i) Internet sources

      (a) Climate data, including downscaled projections from climate models that were generated for other assessments

      (b) Vulnerability assessments that have been done for a given area or sector, including national reports on climate change

(c) Climate-related analyses done for the road sector in the country or region, including project documents for climate adaptation projects

(ii) Relevant and related project documents

(a) Understanding and interpretations of risks and vulnerabilities and recommendations as given in other road projects in India
(b) Engineering upgrade responses and cost estimates as prepared in the design report of the project road, such as
   (1) engineering surveys and investigation reports that uncover current structural deficiencies with regard to project roads, and
   (2) relevant chapters in the DPRs that deal with structural designs that deviate from normative practices with the intention to alleviate future climate change risks and vulnerabilities.

III. PROJECT AREA DESCRIPTION

A. General Physiography of Maharashtra

24. The state of Maharashtra is broadly divided into six physiographic divisions (Figure 1) based on distinct altitude and topographical, climatic, and vegetative characteristics: (i) Sahyadri and its transverse ranges, (ii) Maharashtra plateau, (iii) Northern hills of the Satpudas system, (iv) Tapi–Purna lowland, (v) Wardha–Wainganga–Pranhita alluvial land, and (vi) Konkan coastal lowland.6

25. The Western Ghats, also known as Sahyadri, is the chain of mountains extending southwards from Tapi river in north Maharashtra to the southmost tip of the Indian peninsula. It runs almost parallel to the coast and forms the physical backbone of Maharashtra, with an average height of 1,200 meters (m) above mean sea level. The Maharashtra Plateau, also known as the Deccan Plateau, ranges from 500 m to 1,000 m in elevation. This tableland is composed of old and stable landmass characterized by accumulation of volcanic rocks, principally basaltic lavas. The Satpuda hills in northern Maharashtra run in an east–west direction and are characterized by parallel rift valleys of the rivers Narmada and Tapi. The Tapi–Purna lowlands are broad, gently inclined troughs bordered by the Ajanta hills in the south and the Gavilgad hills in the north. The Wardha–Wainganga–Pranhita alluvial lands are located mainly in the eastern part of Maharashtra, bounded on three sides by higher lands such as the hills of Satpuda to the north, the Maharashtra plateau to the west, and Chhattisgarh to the east. The Konkan coastal lowland is the narrow tract of land between the Western Ghats and the Arabian Sea. It is characterized by uneven topography consisting of transverse ridges with varying elevations, isolated hills, low-lying plateaus, and narrow rivers.

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6 Chapter II, Physiography of the Region; Maharashtra State, India.
B. Maharashtra State Road Improvement Project Locations

26. Road infrastructures are sensitive to increasing and critical risks from climate-driven stressors due to ambient and periodic extremes in temperature, precipitation, and their aftermath such as consecutive days of extreme heat, floods exceeding certain levels, and landslides. Knowing the risks associated with the location of the road due to future climate change is an important part of adaptation decision.

27. The 13 MSRIP project roads are widely scattered in various districts of Maharashtra with various physiographic and climatic variations. The state is divided into nine agro-climatic zones, differentiated mostly by rainfall, soil types, and cropping patterns. Rainfall patterns in Maharashtra vary considerably. The area west of the Ghat mountains (Konkan lowlands) receives heavy monsoon rains with an annual average of more than 3,000 millimeters (mm). However, just 150 km to the east, in the rain shadow of the mountain range, are drought-prone areas where only around 500–700 mm/year of rainfall is available annually and long dry spells are common. The far eastern zones are characterized by moderate to high rainfall patterns. The average annual rainfall in the state is 1,181 mm and 75% of it is received during the southwest monsoon in June to September.

28. The climatic characteristics of the nine main agro-climatic zones are summarized in Figure 2. The locations of various districts of Maharashtra in relation to climatic zones are also indicated. The road project packages (Table 1) are indicated in terms of their length, location by districts, and climatic zones.

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29. Four road projects, EPC 1a, 1b, 2a, and 2b located in Ratnagiri district, fall in the South Konkan Coastal Zone that is characterized by high rainfall in excess of 3,000 mm/year. Precipitation is mainly driven by the southwest monsoon that occurs during June to September. The higher average maximum temperatures range from 30°C to 35°C.

30. Three road projects, EPC 3, 4, and 9 located in Solapur district, fall in the Western Drought Prone Zone that is characterized by low and unpredictable rainfall of 500–700 mm/year in 40–45 days. Common dry spells usually last 2 to 10 weeks annually. Delayed onset and early cessation of the southwest monsoon are also very common. Summer temperatures will usually reach above 42°C in this dry region.

31. Located in the Moderate Rainfall Zone are road projects EPC 5 and 6. This zone is characterized by an annual total rainfall of about 1,200 mm/year that occurs during the southwest monsoon months of June through September. Maximum temperatures hover in the range of 35°C–40°C during summer. These project roads connect the districts of Akola, Amravati, Yashim, and Yavatma.

32. Four road projects, EPC 7a, 7b, 8a, and 8b in the districts of Akola and Amravati, fall in the Assured Rainfall Zone where rainfall of 700–900 mm/year is distributed as dictated by the southwest monsoon. Maximum summer temperature reaches about 40°C in this area.
IV. CLIMATE, OBSERVED TRENDS, AND CLIMATE CHANGE IN MAHARASHTRA

A. The Baseline Climate

33. The climate diagrams presented below are based on 30 years (from 1985 onwards) of weather data and model simulations. They give good indications of typical climate patterns and expected conditions (temperature, precipitation, sunshine, and wind). The simulated weather data have a spatial resolution of approximately 30 km but do not represent all local weather effects such as thunderstorms, local winds, or cyclones.

34. Figure 3 illustrates the average monthly baseline information in terms of two important climatic variables—temperature and precipitation—for representative districts where the MSRIP roads are located. The solid red line shows the maximum temperature of an average day for every month in the project districts. The solid blue line shows the average minimum temperature. Hot days and cold nights (dashed red and blue lines) show the average of the hottest day and coldest night of each month of the last 30 years, respectively.

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8 Meteoblue. Climate diagrams (accessed on 26 September 2019).
B. Observed Climate Trends

35. The India Meteorological Department (IMD) maintains a nationwide network of meteorological stations and provides climatic observations and products to national agencies as well as international agencies such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). The information in the following paragraphs on observed climate trends for the state of Maharashtra is sourced from an IMD publication, Climate Profile of India, derived from long-term, reliable datasets (1951–2010) from 282 stations for temperature and 1,451 stations for rainfall series across the nation. The publication is meant to provide insight into climate change occurring over smaller regions and to assist the states in the formulation of their adaptation and mitigation strategies in light of rapidly changing climate trends.

1. Temperature Trends

36. State-level annual and seasonal mean maximum temperature and mean minimum temperature trends based on 33 surface meteorological stations in Maharashtra state for the observed period 1951–2010 are shown below. Increasing trend is indicated by a (+) sign and decreasing trend by a (-) sign. The asterisk (*) indicates significant trend at 95% confidence level.

**Table 2: Temperature Trends in the Maharashtra State
(°C per year)**

<table>
<thead>
<tr>
<th>Temperature Trends</th>
<th>Annual</th>
<th>Winter</th>
<th>Summer</th>
<th>Monsoon</th>
<th>Post-Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Maximum</td>
<td>+0.01*</td>
<td>+0.01*</td>
<td>+0.02*</td>
<td>+0.01*</td>
<td>+0.02*</td>
</tr>
<tr>
<td>Mean Minimum</td>
<td>No Trend</td>
<td>No Trend</td>
<td>-0.01</td>
<td>No Trend</td>
<td>+0.01</td>
</tr>
</tbody>
</table>

C = centigrade.  
Source: IMD, Government of India

2. Rainfall Trends

37. State-level annual and seasonal rainfall trends based on 142 rainfall stations in Maharashtra state for the observed period 1951–2010 are shown in Table 3. Note that the

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increasing trend is indicated by a (+) and the decreasing trend by a (-) sign. The asterisk (*) indicates significant trend at 95% confidence level.

<table>
<thead>
<tr>
<th>Table 3: Rainfall Trends in the Maharashtra State (mm per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual</strong></td>
</tr>
<tr>
<td>-0.71</td>
</tr>
</tbody>
</table>

mm = millimeter.
Source: IMD, Government of India

3. Daily Climatic Extremes of Temperature and Precipitation in Maharashtra

38. From a historical perspective, the record maximum and minimum temperatures, and 24-hour heaviest rainfall up to year 2010 for meteorological stations of interest in Maharashtra are in Table 4. Dates of occurrence of extremes are also shown.

Table 4: Some Historical Highlights of Extremes Ever Recorded (up to 2010)

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Highest Maximum Temperature, °C</th>
<th>Highest Maximum Temperature, °C</th>
<th>24-hour Heaviest Rainfall, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(dd/mm/yy)</td>
<td>(dd/mm/yy)</td>
<td>(dd/mm/yy)</td>
</tr>
<tr>
<td>Akola</td>
<td>47.8 (22 May 1947)</td>
<td>2.2 (9 Feb 1887)</td>
<td>365.4 (15 Sep 1959)</td>
</tr>
<tr>
<td>Amravati</td>
<td>48.3 (6 May 1988)</td>
<td>5.0 (9 Feb 1887)</td>
<td>234.9 (15 Sep 1933)</td>
</tr>
<tr>
<td>Ratnagiri</td>
<td>40.6 (29 Mar 1982)</td>
<td>11.6 (9 Feb 2008)</td>
<td>637 (31 May 2006)</td>
</tr>
<tr>
<td>Solapur</td>
<td>45.6 (1 Jun 1923)</td>
<td>4.4 (7 Jan 1945)</td>
<td>191 (2 Aug 1940)</td>
</tr>
<tr>
<td>Yavatmal</td>
<td>46.6 (5 Jun 1995)</td>
<td>6.2 (19 Dec 2010)</td>
<td>220.6 (21 Sep 1981)</td>
</tr>
</tbody>
</table>

C = centigrade, mm = millimeter.
Source: IMD - Pune, Government of India

39. A recent study on changes in hot and cold extremes over Maharashtra and Karnataka states of India acknowledges widespread warming through the increase in intensity and frequency of hot weather events and the decrease in frequency of cold weather events. Daily maximum and minimum temperature data from 21 meteorological stations for the period of 1969–2006 were analyzed for extreme indices based on percentiles. The criteria adopted for categorizing extreme temperature indices were $TMAX \geq 99p$ for extremely hot days, $99p > TMAX \geq 95p$ for very hot days, $95p > TMAX \geq 90p$ for hot days, $TMIN \leq 5p$ for very cold nights, $5p < TMIN \leq 10p$ for cold nights, and $10p < TMIN \leq 15p$ for moderately cold nights.

40. The upper maximum temperature is of concern for the project roads located in the tropical climate zone, and the findings from the above cited study on maximum temperature trends are replicated here (footnote 7). In terms of extremely hot days during the summer season, $TMAX \geq 99p$, around 70% of stations showed increasing trends with the remaining 30% of stations showing decreasing trends. In terms of very hot days, $99p > TMAX \geq 95p$, around 62% of stations showed rising tendency in very hot days and 38% of stations recorded falling trends. Similar pattern with different rates was observed in hot days, $95p > TMAX \geq 90p$. In summary, the cited

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10 Indian Meteorological Department, Pune. *Ever Recorded Extremes up to 2010.*

study concludes that the number of days with higher temperatures are increasing over most of the study area.

C. Future Climate Projections – SRES A1B

41. For years, scientists have been using sophisticated computer models, such as general circulation, atmosphere–ocean interaction, and radiative–convective process models, in attempts to visualize the future of the Earth’s climate. The output of a particular model can be enlightening, and combining data from multiple models and sources, both past and future, gives the most comprehensive and dependable vision of what the future holds.

42. The Maharashtra state recently came up with a document, Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra (MSAPCC 2018) (footnote 7). The document highlights climate change in Maharashtra with sector-specific impacts, recommendations, and action plans. The climate change projections were built on high resolution modeling for which the consultant, The Energy Research Institute (TERI), entered into a partnership with the United Kingdom Meteorological Office (UKMO). Four ensemble simulations using the PRECIS model for SRES A1B scenario for the baseline time period (1970–2000) and the future time period (2021–2040) have been used for the analysis. The observation data used for validation of these models were from the IMD: 1x1 degree gridded dataset of rainfall in 1951–2007 and temperatures (mean, maximum, and minimum) for 1969–2005. Using the UKMO Regional Climate Model (RCM), projected changes in temperature and rainfall across the state given at a resolution of about 25 km by 25 km are for the time periods 2030s, 2050s, and 2070s—with the average climate during 1970–2000 taken as the model’s baseline.

43. The MSAPCC 2018 discusses the impact of climate change on six sectors—(i) agriculture, (ii) water resources, (iii) health, (iv) forests and biodiversity, (v) livelihoods, and (vi) energy and infrastructure. It also makes projections for rainfall and temperature in the Maharashtra state and assesses the future sea level rise. A chapter in the document is dedicated to extreme rainfall, flooding, and adaptation in the Mumbai Metropolitan Region.

44. **Temperature projections.** The spatial temperature change in the 2030s in Maharashtra indicates difference in warming over different regions of the state. The annual mean temperature is projected to increase by 1.2°C–1.5°C in the Vidarbha region and in the Marathwada and Nasik regions as compared to the Pune and Konkan regions where the increase in temperature is projected to be 1°C–1.2°C. The mean maximum temperature in the Vidarbha and Marathwada regions is projected to increase by 1°C–1.2°C, as compared to the Nashik, Pune, and Konkan regions where the increase in temperature ranges at 0.5°C–1°C. The mean minimum temperature was found to be a little more than the mean maximum temperatures in all regions. An impression of overall changes in temperature in the 2030s is extracted and shown in Figure 4.

45. The extreme temperature projections for the Maharashtra state expressed in terms of “warm nights index” have been taken as the 90th percentile of minimum temperature of the baseline data sets or Tn90p (IPCC 2007). Results show that warm nights are increasing more in the Konkan, Nashik, and Pune divisions of Maharashtra compared to the Aurangabad, Marathwada, and Vidarabha regions (Figure 5).

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12 The Government of Maharashtra appointed The Energy Research Institute (TERI) for the state’s Climate Change Study in 2010.
46. **Rainfall projections.** The percentage increase in the annual total June–July–August–September (JJAS) (monsoon) rainfall in the 2030s with respect to the baseline shows that a few regions in Maharashtra will experience increase in rainfall, especially the north-central region compared to the east, west, and southern regions (Figure 6.a).

47. A common way to analyze changes in extreme precipitation is to follow the evolution of the percentiles of daily precipitation. The extreme rainfall projections for the 2030s (Figure 6.b) for Maharashtra has been expressed in terms of “extreme wet days,” or R99ptot, which is the total annual June–July–August (JJA) precipitation when daily precipitation on a wet day exceeds 99th percentile. The extreme rainfall index shows an increase in all regions with large amount of increase in Aurangabad and the northern regions of Nashik division compared to the Konkan belt and Vidharbha region. It essentially means that Aurangabad and the northern Nashik regions would have higher contribution from extreme rainfall in their total rainfall in the 2030s.
D. Future Rainfall Projections for Maharashtra: RCP Scenario

48. A recent publication on rainfall extremes in the Krishna Basin of India, which covers pretty much the whole of the Deccan plateau encompassing a vast geography of Maharashtra except its western coastal Konkan belt, presents new hydrological insights for the region under future climate scenarios.\(^\text{13}\)

49. The inputs to the study such as rainfall data (0.25°×0.25°) and maximum and minimum temperatures (0.5°×0.5°) used for the model were obtained from the IMD. The other required data such as solar radiation, wind speed, and relative humidity were autogenerated by the soil and water assessment (SWAT) model. The climate data for the historic scenarios (1970–2005) and future scenarios (2006–2100) were obtained from the Earth System Grid Federation (ESGF) (\(\text{https://esg-dn1.nsc.liu.se}\)), i.e., CORDEX-South Asia database. Data from six climate models (ICHES-EC-EARTH, NOAA-GFDL-GFDL-ESM2M, MIROC-MIROC5, NCC-NorESM1-M, IPSL-CM5A-MR, and CNRM-CERFACS-CNRM-CM5) were used, comprising high resolution (0.5°×0.5°) climate data with Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 scenarios. Downscaled and bias-corrected climate models with medium emission (RCP 4.5) and high emission (RCP 8.5) scenarios were used to improve future predictions and model performance.

50. As the CNRM-CM5 showed better statistical relationship with the observed data than the other models, this model with the RCP 4.5 scenario projected a 13%, 7%, and 2% decrease in the long-term mean Indian summer monsoon rainfall (ISM) in the early century (2009–2040), mid century (2044–2070), and end century (2074–2100), respectively. The long-term mean rainfall values for the months of June, July, and September were projected to decrease by 47 mm, 59 mm, and 44 mm respectively for the early, mid, and end century. In contrast, rainfall in the month of October was projected to increase by 22 mm, 45 mm, and 17 mm respectively for the early, mid, and end century. While using the RCP 8.5 scenario, the long-term mean ISM
was projected to decrease by 14% in the early century and to increase by 6.5% and 22% for the mid and end century.

51. In conclusion, the climate model (CNRM-CM5) projected a decreasing trend of rainfall under the RCP 4.5 scenario, whereas under the RCP 8.5 scenario, it predicts a decrease of rainfall in the early century and an increasing trend for the mid and end century.

52. A climate risk and vulnerability assessment done for the Maharashtra Rural Roads Connectivity Project\textsuperscript{14} takes advantage of the World Bank’s Climate Change Knowledge Portal\textsuperscript{15} (CCKP) that enables users to explore future climate indices and to inform decision makers on future risks. The CCKP prioritizes analysis using multimodel ensembles that are robust and have proven to be most successful in representing expected changes.

53. The following district-wise projections for rainfall for Maharashtra (Table 5) are based on the bcc_csm1_1 ensemble (a version of Beijing Climate Center Climate System model), which according to the CMIP5 design runs most of its experiments with outputs that include averages of important climate parameters over a range of time scales, from hours to a full year. The cited report makes no mention of the time frame for which the projections have been derived but seems most likely to be mid-century 2040–2059 projection.

### Table 5: Historical (1986-2005) and Projected (mid-century 2040-2059\textsuperscript{*}) Increase in Rainfall in Regions of Maharashtra, by CMIP5, RCP 8.5 Scenario

<table>
<thead>
<tr>
<th>Month</th>
<th>Nashik Historical</th>
<th>Nashik Projected Increase</th>
<th>Aurangabad Historical</th>
<th>Aurangabad Projected Increase</th>
<th>Amravati Historical</th>
<th>Amravati Projected Increase</th>
<th>Nagpur Historical</th>
<th>Nagpur Projected Increase</th>
<th>Konkan Historical</th>
<th>Konkan Projected Increase</th>
<th>Pune Historical</th>
<th>Pune Projected Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.57</td>
<td>4.53</td>
<td>4.72</td>
<td>9.37</td>
<td>4.72</td>
<td>9.37</td>
<td>13.38</td>
<td>0.47</td>
<td>0</td>
<td>0.06</td>
<td>1.03</td>
<td>6.65</td>
</tr>
<tr>
<td>Feb</td>
<td>0.48</td>
<td>1.68</td>
<td>1.33</td>
<td>0.65</td>
<td>1.33</td>
<td>0.65</td>
<td>16.8</td>
<td>-0.34</td>
<td>0.16</td>
<td>-0.76</td>
<td>0.63</td>
<td>1.7</td>
</tr>
<tr>
<td>Mar</td>
<td>1.33</td>
<td>3.58</td>
<td>2.73</td>
<td>5.38</td>
<td>2.73</td>
<td>5.38</td>
<td>20.08</td>
<td>-1.93</td>
<td>2.19</td>
<td>0.27</td>
<td>1.05</td>
<td>3.89</td>
</tr>
<tr>
<td>Apr</td>
<td>2.83</td>
<td>1.02</td>
<td>2.66</td>
<td>1.65</td>
<td>2.66</td>
<td>1.65</td>
<td>8.07</td>
<td>8.99</td>
<td>17.1</td>
<td>1.78</td>
<td>6.92</td>
<td>1.33</td>
</tr>
<tr>
<td>May</td>
<td>19.32</td>
<td>1.56</td>
<td>20.43</td>
<td>1.62</td>
<td>20.43</td>
<td>1.62</td>
<td>16.07</td>
<td>1.34</td>
<td>37.39</td>
<td>6.57</td>
<td>26.08</td>
<td>2.46</td>
</tr>
<tr>
<td>Jun</td>
<td>138.05</td>
<td>58.77</td>
<td>150.51</td>
<td>65.43</td>
<td>150.51</td>
<td>65.43</td>
<td>168.2</td>
<td>52.98</td>
<td>345.57</td>
<td>74.51</td>
<td>173.78</td>
<td>73.13</td>
</tr>
<tr>
<td>Aug</td>
<td>193.21</td>
<td>55</td>
<td>152.08</td>
<td>45.99</td>
<td>152.08</td>
<td>45.99</td>
<td>284.44</td>
<td>32.45</td>
<td>277.43</td>
<td>170.21</td>
<td>151.14</td>
<td>64.79</td>
</tr>
<tr>
<td>Sep</td>
<td>178.57</td>
<td>15.58</td>
<td>147.89</td>
<td>19.7</td>
<td>147.89</td>
<td>19.7</td>
<td>165.4</td>
<td>21.6</td>
<td>166.16</td>
<td>66.02</td>
<td>156.09</td>
<td>5.42</td>
</tr>
<tr>
<td>Oct</td>
<td>56.52</td>
<td>-11.82</td>
<td>53.51</td>
<td>15.82</td>
<td>53.51</td>
<td>-15.82</td>
<td>62.75</td>
<td>12.84</td>
<td>100.79</td>
<td>6.22</td>
<td>70.75</td>
<td>-12.85</td>
</tr>
<tr>
<td>Nov</td>
<td>8.53</td>
<td>0.34</td>
<td>14.75</td>
<td>-0.37</td>
<td>14.75</td>
<td>-0.37</td>
<td>14.1</td>
<td>0.5</td>
<td>19.62</td>
<td>10.35</td>
<td>11.86</td>
<td>-0.63</td>
</tr>
<tr>
<td>Dec</td>
<td>6.27</td>
<td>-1.59</td>
<td>11.81</td>
<td>-1.1</td>
<td>11.81</td>
<td>-1.1</td>
<td>12.72</td>
<td>4.06</td>
<td>9.8</td>
<td>10.36</td>
<td>10.09</td>
<td>-1.89</td>
</tr>
</tbody>
</table>

*Likely period
CMIP = Climate Model Intercomparison Project, RCP = Representative Concentration Pathway.
Source: Climate Knowledge Portal, World Bank

54. Under Table 5, substantial increases in monthly rainfall are likely to occur during June and August across the state of Maharashtra. Higher increases in monthly rainfall are expected in Konkan and Nagpur that could register 78% and 89% higher than the historical average (1986–2005).

55. A primary concern relating to climate change in MSRIP-1 project roads is that of changes in seasonal and annual precipitation but by far worse would be those impacts by extreme rainfall events under a changed future climate. To conclude on the above, there are as many as 40

\textsuperscript{14} Climate Risk and Vulnerability Assessment (CRVA) for Rural Roads in Maharashtra; Maharashtra Rural Connectivity Improvement Project (RRP IND 52328).
\textsuperscript{15} World Bank, Climate Change Knowledge Portal.
different climate models within CMIP5 that provide estimates of precipitation changes in the future. Unlike for temperature, where models show a general degree of agreement about future regional changes, there is much less agreement about where and how precipitation will change. Nonetheless, projections of future precipitation changes are bound to become more consistent as models continue to improve over time.

V. CLIMATE RISK AND VULNERABILITY ASSESSMENT: MSRIP PROJECT ROADS

A. Hazards and Likelihood Assessment

56. As described earlier, the 13 MSRIP project roads are scattered in various districts of Maharashtra, which are characterized by physiographic and climatic variations. The state has diverse ecosystems with their inherent assortments of risks under climatic as well as non-climatic exposures and with differential vulnerability profiles. The state is prone to various natural disasters such as heat waves, droughts, floods, cyclones, and earthquakes. From a practical perspective, knowing the risks associated with the location of the project due to future climate change is an important part of adaptation decision.

57. A general perspective of natural hazards and risks in Maharashtra (Figure 7) is taken from the web-based tool, ThinkHazard. This tool enables non-specialists to incorporate impacts of disasters in the planning and design of new development projects as it provides a general view of the hazards for a given location. The likelihood of natural hazards such as river flood, urban flood, water scarcity (drought), extreme heat, wild fire, earthquake, cyclone, coastal floods, etc. are identified for a given location with risk levels categorized as very low, low, medium, and high. The hazard levels provided in this tool are reportedly based on published hazard data, provided by a range of private, academic, and public organizations.

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16 ThinkHazard: Developed for informational purposes by the Global Facility for Disaster Reduction and Recovery (GFDRR).
58. With the information from ThinkHazard, this CRVA defines the likelihood levels of risks in probabilistic terms as follows:

(i) **High**: highly likely or >90% chance of a potentially damaging and life-threatening hazard event occurring at least once in the next 10 years

(ii) **Medium**: likely or >66% chance of potentially damaging hazard event occurring in the next 10 years

(iii) **Low**: <33% chance of a potentially damaging hazard event occurring in the next 10 years

(iv) **Very Low**: almost non-existent and, even if it does occur, is associated with an extremely low probability or <10% of occurrence

B. Exposure and Sensitivity

59. Figure 7 shows that extreme heat affects all project districts with a high level of risk due to the location of the project areas within the tropical belt. Heat waves in Maharashtra occur sporadically in various interior regions, thus impacting the structural integrity of the exposed road pavements. Another concern is flooding, both coastal and riverine. Flooding is a highly localized phenomenon and flood hazards can vary dramatically over short distances, depending on local topography, drainage capacity, and distance to waterways. While Ratnagiri, located in the high rainfall zone of western Maharashtra is prone to floods and landslides, the low rainfall districts of the state are under constant risk of droughts. With these considerations on road infrastructure, the following extreme climate conditions and their impact are discussed.

60. **Exposure to Extreme Heat**

(i) **Road pavement.** The highway pavements are totally exposed to natural elements but separating the main factors for wear and tear of highway pavements by weather conditions and traffic is rather difficult.

Figure 7 shows that the risk on road pavements by extreme heat is high. According to the IMD, heat wave is defined when daily maximum temperature exceeds the average maximum temperature by 5°C persistently for more than 5 consecutive days. Alternately, it is defined as when the maximum temperature of a station reaches at least 40°C or more for plains, 37°C or more for coastal regions, and at least 30°C or more for hilly regions. In Figure 1, the average monthly maximum temperatures are seen to exceed 40°C in all the project road locations during the pre-monsoon months. Further as shown in Section IVB, the districts of Akola,

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17 Indian Meteorological Department, Government of India. All India Heat Wave Information.
Amravati, Solapur, and Yavatmal have at one time exceeded 45°C into the range of “severe heat wave” as per the IMD’s definition.

High temperatures and heat waves impact road pavement integrity, causing road surface failures by softening, and traffic-related rutting and cracking. It is also recognized that oxidation and the action of UV radiation cause excessive hardening of the asphalt close to the pavement surface and brittleness of the material over time. Hotter weather will speed up the oxidation process and make the material more vulnerable to cracking. Cooler diurnal temperatures will generate thermal tensile stresses that cause crack initiation and propagation.

(ii) **Bridges.** During the structure’s lifetime, bridges are subjected to daily, seasonal, and yearly repeated cycles of heating and cooling induced by solar radiation and surrounding air. Since bridges expand and contract due to temperature changes, bearings and expansion joints are usually employed to accommodate movements. These movements in the bridge may seem initially insignificant, but with pervasive changes induced by extreme heat, the bridge may eventually start to deform and fail.

61. **Exposure to Extreme Precipitation**

(i) **Flooding.** The observed perplexing (1951–2010) rainfall trends given in Section IVB could be attributed to disparities in the magnitude of changes that have taken place in different rainfall seasons and different spatial locations. Section IVC notes that extreme rainfall in future decades is projected to increase in all regions of the Maharashtra state with greater increases in the northern parts. This will lead to heavy flooding, which will definitely impact the state’s road infrastructure. Furthermore, this problem is particularly acute on roads in urban areas owing to the high proportion of impermeable surfaces that prevent infiltration of water into the soil. This results in uncontrollable overland flow that causes drains to exceed their capacity, and also increases the likelihood of drain blockages.

By the IMD’s definition, a rainfall of over 244.5 mm in 24 hours is considered as “extremely heavy rainfall.” Such intense rainfalls are the main cause of urban floods and flash floods that impact hill slopes resulting in landslides and overwhelm channel equilibrium of roadside drainages. In Section IVB earlier, the districts of Akola, Amravati, Ratnagiri, Solapur, and Yavatmal have recorded rainfall of over 124.4 mm in 24 hours, which is the IMD’s threshold for “very heavy rain.” At one instance on 31 May 2006, the coastal district of Ratnagiri recorded a high of 637 mm of rainfall within 24 hours.

(ii) **Landslides.** Rainfall is one of the main triggering factors of landslides. These could be shallow landslides, surface and gully erosion, debris flows, mud slides, and debris slides. Among the districts where the project roads are located, only Ratnagiri is exposed to landslide hazard but is classified low in terms of level of risk. Here, only those roads that navigate across the Western Ghats from Ratnagiri to the interior Maharashtra districts are susceptible to landslides because of this area’s rainfall patterns, terrain slope, geology, soil, land cover, and potentially, earthquakes conducive to landslides.
62. **Exposure to Other Hazards**

   (i) **Cyclones.** The coastal district of Ratnagiri is classified *high* for cyclone hazards, meaning that there is more than a 20% chance of potentially damaging wind speeds in the project area in the next 10 years. It must be noted that damages not only occur due to high velocity winds but also to heavy rainfall and subsequent flooding, which include coastal floods.

   (ii) **Earthquakes and tsunamis.** From a geo-tectonic perspective, the 1,200 kilometer-long Makran subduction zone in the Arabian Sea is assessed as potential future sources for great earthquakes that can generate tsunamis affecting the west coast of India. It has also been inferred that lateral transition between subduction and collision of the Indian and Arabian tectonic plates has made Bombay, Cambay, Kutch, and Namacia Grabens in northwestern India susceptible to tsunamigenic earthquakes. It is also suggested that earthquakes associated with thrust and subidence faulting in the coastal region of the Kutch, which runs along the west coast of Maharashtra, have the potential of generating local tsunamis.

   In Ratnagiri, tsunami hazard is classified *medium*, meaning there is more than a 10% chance of a potentially damaging tsunami occurring in the next 50 years. Thus, the impact of tsunami should be considered in different phases of the project for any development activities, including roads located near the coast.

### VI. PROPOSED ADAPTATION ACTIONS AND COSTS

#### A. Synopsis

63. A significant part of climate proofing takes place at the project level to ensure that a project’s design is apt for projected climatic condition. According to ADB guidelines (footnote 4), the development of the adaptation strategy is best integrated into the activities of the project preparation technical assistance team, following the identification of potential risks due to climate change during the concept stage.

64. It must be recognized that there is no permanent “fix” to climate change vulnerabilities. Adaptation measures, if necessary, can be achieved in later development cycles based on experience and emerging information. Given the many uncertainties and costs involved, it is not easy to make decisions nor is it possible or even necessary to do every visualized adaptation measures at once.

65. The goal of adaptation assessment is to identify and prioritize the most appropriate measures for the investment project. Adaptation options in the transport sector may generally be grouped into engineering (structural) options and non-engineering options. Often, due to information gaps and resulting uncertainties, conclusions from the impact, vulnerability, and adaptation assessments may indicate that doing nothing (no climate proofing) could be the best course of action (footnote 4).

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66. Non-engineering options of climate change adaptation for the project roads are examined in the initial environmental examination (IEE) reports. Effects of human activities on the environment is an increasing concern and the IEE looks into reducing the vulnerabilities and building resilience of people and nature to the current and anticipated effects of climate change. The IEE addresses bio-physical drivers of vulnerabilities such as unwholesome land management practices, deforestation, and detrimental agricultural and cropping patterns. The IEE also exposes geophysical vulnerabilities such as slope instability, erosion, flood risks, etc. and recommends risk mitigation or adaptation measures in the project design.

67. The final detailed designs for MSRIP roads are already prepared. Two major types of climate-related risks to road infrastructure are those driven by long-term changes in temperature and precipitation. This CRVA looks at aspects of engineering adaptation measures against climate change risks, which include road surface and sub-grade durability, materials specifications, drainage structures and dimensions, erosion measures, protective engineering structures, cross-sections, and other innovative features. Among the design documents for each MSRIP road, of particular interest in this CRVA are (i) engineering surveys and investigation reports that reveal current structural deficiencies, and (ii) sections in the DPRs that deal with innovative structural designs meant to address future climate change risks and vulnerabilities.

68. Understanding that the Maharashtra Public Works Department (MPWD) has first-hand knowledge about the extent to which climate stressors have affected current road infrastructures in their jurisdiction, a consultation meeting and a field visit were conducted from 25 June to 3 July 2019 (Appendix 2). The MPWD Project Directorate officials and some members of the design team present at the meeting were fully aware that climate change might produce new kinds of hazards and threats to their road assets in the long run. According to them, the structural designs carried out in the MSRIP address current road performance problems and deficiencies (lessons learned), with the idea to build resilience to climatic hazards. The MPWD officials stated that they have provided substantive information, inputs, and guidance to the road design engineers with the objectives to mitigate and to adapt to climate-induced vulnerabilities to the best extent possible.

69. Prior to detailed design preparation, surveys were carried out in all project roads through visual inspections, dimensional measurements, and investigative tests based on the Indian Roads Standard IRC-SP:19. The resulting inventories have captured the condition and data on terrain, carriageway width and surfacing, shoulder type and widths, existing pavement layer composition and thicknesses, soil types, road subgrade and texture classification, horizontal and vertical geometries, retaining structures, heights of embankments, drainage types and conditions, right-of-way widths, and ancillary utilities along the road.

70. According to the MPWD, the philosophy behind the detailed designs of the MSRIP roads is ensuring that adequate considerations have been taken to address current deficiencies in terms of road geometries, road foundation integrity, and providing structures such as road drains, culverts, and small bridges based on their initial assessments of the condition of existing road assets.

71. MSRIP sample field visits were conducted (27 June–1 July 2019) in the districts of Ratnagiri and Solapur, where project roads under EPC 1, 2, 3, 4, and 9 (Figure 2) were visited. Besides logistic constraints, sample roads were chosen to represent locational aspects as distinguished by climatic and physiography variations. Windward side Ratnagiri represents a high

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19 Engineering Surveys and Investigations, Chapter 3, Final Detailed Project Report, MSRIP.
rainfall zone (>3,000 mm/year), with portions of its project roads running through elevated terrain in the Western Ghats. Leeward side Solapur located in the Deccan Plateau represents primarily a rain shadow region characterized by low and unpredictable rainfall of 500–700 mm/year, frequented by dry spells usually lasting for several weeks annually and representative of the remaining project districts of Akola, Amravati, Washim, and Yavatmal.

72. The road pavement is a very important component in road design. Aside from being able to support the projected future traffic loads, it needs to withstand the impacts of climatic extremes over its design life. The characteristics of subgrade materials for base courses and bitumen determine structural strength, impact of climate, and durability aspects. Based on the test results of the existing roads, a minimum California Bearing Ratio (CBR) of 10% has been adopted as much as possible in the improvement design. Stretches of road with poor subgrade and embankment materials are to be excavated and replaced with durable quality materials meeting CBR values of 8%–10%. Overall, the pavement works for the MSRIP projects include (i) strengthening of the existing pavement, (ii) reconstruction over the existing pavement, and (iii) construction of new pavement for realigned and widened portions.

73. Asphalt mixtures for road pavements consist of optimum combination of the aggregate (various fractions) and asphalt binder (bitumen), and other optional additives. Increasing temperature affects the behavior and performance of bitumen bonded materials. The most common distress in bituminous asphalt roads are rutting (depressions or grooves worn into the road as a result of traffic load and high temperatures where asphalt pavements deform), cracking, ravelling (individual aggregate particles of top layer dislodged from the pavement surfaces), and stripping. The surveys of existing conditions (footnote 10) have inventoried road pavement surface distresses of MSRIP roads such as cracking, ravelling, potholes, rut depths, edge breaks, and patching following the IRC:SP:19-2001.

74. With recent advances in bitumen technology and manufacturing in India, the Bureau of Indian Standards (BIS) recommended in its fourth revision (IS 73: 2013) the use of viscosity-graded VG-30 paving bitumen in lieu of 60–70 penetration grade used earlier in most state highways of India. This revision rationalized the binder selection process by categorizing the binder grade based on design maximum air temperature. The VG-30 grade is recommended for application in areas where maximum ambient temperatures hover in the range of 38°C to 45°C.

75. VG-30 grade is especially used to construct extra heavy-duty bitumen pavements that need to tolerate significant traffic loads as well as distresses induced by higher temperatures. The designs use VG-30 instead of the 60–70 penetration bitumen grade used earlier. The pavement design life chosen for the MSRIP roads is 15 years as recommended by IRC: 37-2012.

76. Short-term adaptation measures below can address climate change impacts iteratively as this approach reduces the risk of committing to expensive investment at the beginning of the project cycle. Such can be tackled through improved maintenance practices supported by a flexible budget that responds to changes in volumes or activities rather than a static budget where fixed amounts are earmarked on an annual-use basis.

   (i) Preventive maintenance management where visible deterioration of the project roads in the form of asphalt pavement ravels and cracks, ruts, potholes, and

20 An investigative test used to evaluate the subgrade strength of roads and pavements. The CBR test determines the material properties for pavement design.
embankment and drainage conditions are monitored regularly and remedied
immediately before they have a serious impact on the integrity of the road.

(ii) Adaptive maintenance management that provides for incremental adaptation
actions, implemented over short timescales based on increasing knowledge of
climate change impacts.

77. In line with the preceding paragraph, the MPWD has recently issued a repair and
restorative maintenance order (Circular No. 2016/C.No.165/Planning-1A, dated 03 May 2017)
that mandates the repair of state roads by the seventh year and repair and strengthening by the
15th year, as supported by frequent inspections and immediate repairs of developing distresses.

78. Any bridge structure must pass the anticipated floods without endangering its structural
integrity. As such, hydrological assessments are required to determine the design flood and other
design parameters (e.g., flow velocity, high flood level [HFL], scour depth, etc.). Upgrading of
major bridges (>60m) along the project roads are considered outside the scope of the MSRIP,
but other hydraulic structures such as culverts (<6m) and minor bridges (6m to 60m) are included.
The DPRs show that detailed cross-sectional and longitudinal surveys were undertaken at each
bridge location for modelling high flood profiles for the determination of soffit levels for bridge
reconstruction.

79. The design flood for bridge structures in the MSRIP follows regional flood estimation
guidelines prepared by the Central Water Commission of India in conjunction with relevant
updated Indian Roads Congress (IRC) structural design guidelines. At least four flood estimation
methods were employed and the method with the highest value was taken as the peak design
flood.

80. The sampled roads falling in undulating terrain of Ratnagiri were observed to be free from
severe damaging impacts such as landslides, erosion, washouts, subsidence, and sub-grade
failures. Many culvert bridges and small bridges along those routes were observed to be intact
from impacts of past flash floods, although scouring was conspicuous. Deeper scours
(undermining) at abutments and pier footings have been restored during their seasonal
maintenance routines. In the case of Solapur, almost all the roadside drains, culverts, and small
bridges along the sampled roads were dry at the time of visit although high water level marks from
recent past flood discharges could be observed at some bridges in several locations.

81. In general, road embankment heights in low dipping areas approaching natural drainage
crossings of culverts and small bridges need to be improved. Culverts and small bridges need to
be upgraded to accommodate projected larger flood flows.

B. Climate Change Adaptation Measures in MSRIP

82. The core of adaptation to negative impacts of both climatic and non-climatic risks is to
ensure that all roads are constructed with good quality materials and founded on robust
groundwork. As the MSRIP implementing agency, the role of the MPWD is effective project
management and supervision to guarantee intended long-term benefits from the investment.

83. Road infrastructures face two main climate-related risks as consequences of long-term
changes in the climate, particularly temperature and precipitation. For relatively short cycle assets
such as road pavements, long-term climate changes pose less of a challenge, since the life cycle
is shorter than the time it takes for significant changes in temperature or precipitation to occur.
The exceptions to this are bridges and major drainage assets, which have long service lives and, therefore, early adaptation consideration is the rational course of action.

84. Climate change is the leading cause of the increase in floods and storms, especially in the Indian subcontinent. Section IVC noted that extreme rainfall in future decades is projected to increase in all districts of the Maharashtra state. Project roads in Ratnagiri district are the most vulnerable to extreme rainfall due to its geography. However, under a changed future climate where anomalies and spatial variabilities in precipitation can result in extreme events and intensities, even the generally arid districts of Akola, Amravati, Solapur, and Yavatmal cannot be deemed as safe. Thus, the design of drainage assets in project roads in the drought-prone districts is also considered for upgrading based on assessments of current conditions. The following are the climate change adaptation measures incorporated in the MSRIP.

85. **Upgrade in road and bridge deck pavement design.** By virtue of exposure to the forces of nature, even short-lived assets such as pavements are likely to face some extreme weather events within their life cycle. Section VA pointed out that all project roads are exposed to the effects of extreme high temperatures. One of the major problems associated with paving bitumen is its sensitivity to temperature, with tendencies to become brittle in cold weather and to bleed in hot weather. To deal with the impacts of temperature, Section VIB pointed out that VG-30 grade instead of 60–70 penetration grade bitumen has been adopted.

86. **Improvements in drainage design.** Following are the design improvements for drainage structures and small and minor bridges. (Note: quantities and dimensions of each adaptation measure in each of the 13 project roads are not provided here; for details, please refer to the detailed design reports.)

(i) **Drainage.** The MSRIP includes improvement of drainage structures sized accordingly to cope with higher flooding frequency and magnitude based on updated hydrological assessments, thus improving the hydraulic capabilities of structures such as cross-drains and longitudinal drains, culverts, and small bridges along the project roads. Accordingly, the following are incorporated:

(a) cross drainages of Ø900 mm hume pipes used earlier throughout the project roads are to be replaced by Ø1200 mm; and
(b) depending on the location and vulnerability, some of the hume pipes are to be replaced by box-type culverts, and some others are to be replaced by larger capacity culverts.\(^{21}\)

(ii) **Small and minor bridges.** Small and minor bridges along the project roads are planned to be reconstructed to meet the general requirements of double-laning of existing single-lane roads. The design of small project bridges follows IRC design specifications SP:013 that set minimum vertical clearances in the range of 150 mm to 1500 mm based on design flood discharges, and allow the designer to select higher clearances exceeding the minimum depending on site-specific vulnerabilities and ground surveys. Section VIA mentioned that detailed cross-

\(^{21}\) Some may argue that provision of larger clearances of hume pipes and culverts particularly for roads running through flat arid (drought-prone) regions would serve no purpose. But for the MSRIP, it was decided to maintain uniformity of design of cross drains, which is sensible to meet the unforeseen rigors of a changed future climate.
sectional and longitudinal surveys were undertaken at each bridge location for modelling high flood profiles and selection of bridge geometries.

87. **Other considerations such as vertical alignment.** As a result of upgrading of subgrade, sub-base, and pavement thicknesses, the project roads will generally be raised by approximately 0.3 m throughout the entire stretch. There are critical sections, however, where the road dips and areas where the road embankment must be raised to prevent water stagnation and flooding impacts. The road inventory has identified a total of 23.5 km of such critical areas requiring building up of embankments to overland flood-safe levels.

C. **Costs of Climate Change Adaptation Measures**

88. For simplicity, the total cost of civil works is taken as the sum of cost of structural civil works had climate change measures not been considered in the design of civil structures, denoted here as business-as-usual (BAU) cost, and the additional cost arising from climate change adaptation measures, denoted here as CC adaptation cost.

89. The adaptation measures in MSRIP are priority actions based on justifications made in Section VIB. The estimated associated costs of improvements are presented in able 6 as sum of BAU civil costs and the incremental costs from planned climate change adaptation measures (CC costs) for the MSRIP. In total, the BAU civil works cost is estimated to be ₹ 12,343.8 million, which is about 70.5% of the total project cost which stands at ₹ 17,502.9 million. The total climate change adaptation cost is estimated at about ₹ 979.75 million, which is about 7.94% of total cost of civil works.
Table 6: Overview of Break-up of Climate Change Adaptation Costs for MSRIP

<table>
<thead>
<tr>
<th>Road #</th>
<th>Package #</th>
<th>MRIP-1 Project Roads</th>
<th>Total Road Length in km</th>
<th>Total Project Cost, Million INR</th>
<th>Total Cost of Civil Works, Million INR</th>
<th>Total Cost of Civil Works as % of Total Project Cost</th>
<th>Total Climate Change (CC) Adaptation Cost, Million INR</th>
<th>CC Increment Cost as % of Total Cost of Civil Works</th>
<th>CC Adaptation #1: Improvement of Flood Discharge Capacities of Drainage Assets including Protection Works</th>
<th>CC Adaptation #2: Improvement of Road Embankment Heights in Critical Sections</th>
<th>CC Adaptation #3: Improvement of Flood Drainage Capacities of Small Bridges and Culverts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EPC 1</td>
<td>Improvement of NH-66 to Kante Tulsi Doshi Marleshwar Kukaladora (with Marleshwar Branch) Road SH174</td>
<td>23.58</td>
<td>792.67</td>
<td>538.73</td>
<td>68.8%</td>
<td>25.85</td>
<td>4.90%</td>
<td>12.39</td>
<td>47.9%</td>
<td>1.10</td>
</tr>
<tr>
<td>2</td>
<td>EPC 5</td>
<td>Improvement to Chafe Gampatpule road MDR-55</td>
<td>10.36</td>
<td>300.75</td>
<td>211.40</td>
<td>70.3%</td>
<td>18.21</td>
<td>8.01%</td>
<td>10.73</td>
<td>58.9%</td>
<td>1.26</td>
</tr>
<tr>
<td>3</td>
<td>EPC 2</td>
<td>Improvement of Dabhate Shiposhi Karle Vatal Road joining to NH-17, SH-175</td>
<td>28.10</td>
<td>820.45</td>
<td>549.31</td>
<td>67.0%</td>
<td>68.30</td>
<td>11.89%</td>
<td>48.60</td>
<td>74.4%</td>
<td>0.40</td>
</tr>
<tr>
<td>4</td>
<td>EPC 4</td>
<td>Improvement of Hativalle Jalapur Road SH-170</td>
<td>23.70</td>
<td>626.99</td>
<td>444.50</td>
<td>70.9%</td>
<td>15.46</td>
<td>3.48%</td>
<td>7.08</td>
<td>45.8%</td>
<td>0.30</td>
</tr>
<tr>
<td>5</td>
<td>EPC 6</td>
<td>Improvement of Barshi Sholapur Akalkot Dushani Ainaud to State border Road SH204 (Part Barshi to Sholapur SH204)</td>
<td>61.90</td>
<td>2,509.94</td>
<td>1,761.43</td>
<td>70.2%</td>
<td>103.57</td>
<td>5.88%</td>
<td>71.12</td>
<td>68.7%</td>
<td>1.15</td>
</tr>
<tr>
<td>6</td>
<td>EPC 7</td>
<td>Improvement of Daund Karma Paundra Barshi Osmanabad Road SH8</td>
<td>50.54</td>
<td>2,506.05</td>
<td>1,761.54</td>
<td>70.3%</td>
<td>202.79</td>
<td>11.51%</td>
<td>167.22</td>
<td>92.3%</td>
<td>1.00</td>
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<td>7</td>
<td>EPC 5</td>
<td>Improvement to Shirmpur Vajapur Road Washim-Pushad Futuranag Mandu Road (section Washim-Pushad) in Washim &amp; Yavatmal District SH-81</td>
<td>58.05</td>
<td>1,861.55</td>
<td>1,318.80</td>
<td>70.8%</td>
<td>112.49</td>
<td>8.53%</td>
<td>90.11</td>
<td>80.1%</td>
<td>1.45</td>
</tr>
<tr>
<td>8</td>
<td>EPC 6</td>
<td>Improvement to Riddhapur Teesa Kucha Anjarsinghi Dhamaongan Rly Devgaon Bhabulgaon Road SH-300 (km 40/000 to 10/800) and Dhamaongan Bypass Road (km 0/000 to S/400) TO Teesa District Annawad &amp; Ya</td>
<td>64.66</td>
<td>2,338.26</td>
<td>1,699.65</td>
<td>71.4%</td>
<td>117.93</td>
<td>7.06%</td>
<td>24.20</td>
<td>20.5%</td>
<td>5.90</td>
</tr>
<tr>
<td>9</td>
<td>EPC 7</td>
<td>Improvement to Valgana Daryapur Atul SH17/Road (Daryapur to Atul) District Annawad &amp; Akola, District Amravati &amp; Akola</td>
<td>24.00</td>
<td>1,084.38</td>
<td>766.31</td>
<td>70.7%</td>
<td>50.27</td>
<td>6.56%</td>
<td>14.94</td>
<td>29.7%</td>
<td>1.84</td>
</tr>
<tr>
<td>10</td>
<td>EPC 8</td>
<td>Improvement to Anjli Runnochhan Asara Road (section Daryapur to Asara) District MDR-21</td>
<td>17.55</td>
<td>877.57</td>
<td>620.89</td>
<td>70.8%</td>
<td>59.85</td>
<td>9.64%</td>
<td>9.90</td>
<td>16.5%</td>
<td>1.78</td>
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<tr>
<td>11</td>
<td>EPC 8</td>
<td>Improvement Annawad Chandra Rly Talegaon Road SH297</td>
<td>15.08</td>
<td>604.87</td>
<td>434.45</td>
<td>71.8%</td>
<td>27.27</td>
<td>6.28%</td>
<td>11.17</td>
<td>41.0%</td>
<td>1.10</td>
</tr>
<tr>
<td>12</td>
<td>EPC 9</td>
<td>Improvement to Riddhapur Lehegaon Ner Pimpali Teesa Road SH300</td>
<td>40.80</td>
<td>1,924.36</td>
<td>1,316.05</td>
<td>72.1%</td>
<td>112.74</td>
<td>8.57%</td>
<td>39.57</td>
<td>35.1%</td>
<td>3.96</td>
</tr>
<tr>
<td>13</td>
<td>EPC 9</td>
<td>Improvement to Daund Karma Paundra Barshi Osmanabad Road SH85</td>
<td>35.23</td>
<td>1,365.07</td>
<td>950.74</td>
<td>69.6%</td>
<td>68.02</td>
<td>7.15%</td>
<td>45.27</td>
<td>66.6%</td>
<td>2.20</td>
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<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>401.46</td>
<td>17,502.91</td>
<td>12,343.81</td>
<td>978.75</td>
<td>7.94%</td>
<td>572.32</td>
<td>58.4%</td>
<td>23.44</td>
</tr>
</tbody>
</table>

BAU = business-as-usual, CC = climate change, EPC = engineering, procurement, and construction, INR = Indian rupee, km = kilometer, MDR = major district road, MSRIP = Maharashtra State Road Improvement Project, NH = national highway, SH = state highway.

Source: MPWD
90. **Figure 8** illustrates the total cost of civil works per project road taken sum of BAU costs of civil works and the additional climate change adaptation costs for the 13 project roads. The average BAU civil works cost per km is about ₹25.17 million with an increment of ₹2.17 million per km for climate change resilience.

![Figure 8: Cost of MSRIP Project Civil Cost, (BAU + CC)](source: Asian Development Bank estimates)

91. **T** shows the distribution of climate change adaptation costs (7.94% of total civil cost). Climate change adaptation costs are segregated into three components:

   (i) **CC Adaptation #1** refers to improvement of flood discharge capacities by way of strengthening and increasing dimensions of road drainage assets such as long drains and cross-drain pipes, including protection works. The incremental cost expended here is about 4.64% of the total civil works cost, or 58.4% of total climate change adaptation cost.

   (ii) **CC Adaptation #2** refers to the improvement in vertical embankment heights in certain critical flood-prone sections of projects roads. The incremental cost expended here is about 0.98% of the total civil works cost, or 12.4% of total CC adaptation cost.

   (iii) **CC Adaptation #3** refers to improvement in flood discharge capacities of small and minor bridges. The incremental cost expended here is about 2.32% of the total civil works cost, or 29.2% of total CC adaptation cost.
Figure 9: Proportions of Costs – MSRIP

Source: Asian Development Bank estimates
VII. CONCLUSION

92. The Government of Maharashtra has come up with an official document: Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra (MSAPCC 2018). This highlights climate change in Maharashtra with sector-specific impacts, recommendations, and action plans in areas such as agriculture, water resources, health, forests and biodiversity, livelihoods, and energy and infrastructure. Key adaptation recommendations given are on the integration of future climate change projections and uncertainties into state disaster management plans and disaster risk reduction strategies, including climate proofing of new public infrastructures.

93. A preliminary approach to building resilience to climate change rests in understanding and addressing current weak spots exposed to already known natural hazards that plague operation and maintenance of the existing system. Based on the DPRs for the MSRIP roads, thorough investigations of all project road assets were done. The adaptation measures adopted in the detailed designs are engineering measures mainly as adaptation to extreme precipitation. Some extra costs are involved but the cost of not considering climate change could be higher in terms of traffic disruption and public safety and infrastructure damages needing frequent repairs.

94. Although the general phenomenon of global climate change is widely recognized, prediction and visualization of the impacts of climate change at a local geographical scale remain a challenge. The magnitude of risks from climate change impacts is still highly uncertain yet the high likelihood of some of the impacts is potentially highly disruptive. This highlights the need for planning of adaptive responses to reduce the negative effects. Not all adverse consequences of climate change on road infrastructures can be avoided through adaptation, but the MPWD can significantly reduce the extent of damage through proactive measures to avoid, prepare for, and respond to climate change.
## Glossary of Terms and Terminologies

<table>
<thead>
<tr>
<th>Terminologies used in relation to climate change</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation</td>
<td>Adjustment in natural or human systems to a new or changing environment; a process by which individuals communities, and countries seek to cope with the consequences of climate change.</td>
</tr>
<tr>
<td>Adaptability</td>
<td>The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.</td>
</tr>
<tr>
<td>Adaptation assessment</td>
<td>The practice of identifying options to adapt to climate change effects and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility.</td>
</tr>
<tr>
<td>Adaptation deficits</td>
<td>Largely accounted for by the failure to adapt adequately to existing climate risks largely accounts for the <em>adaptation deficit</em>. As climate change accelerates, the adaptation deficit has the potential to rise much higher unless a serious adaptation program is implemented.</td>
</tr>
<tr>
<td>Adaptation to climate change</td>
<td>Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.</td>
</tr>
<tr>
<td>Climate change</td>
<td>Refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land use.</td>
</tr>
<tr>
<td>Climate change mitigation</td>
<td>Strategies and policies that reduce the concentration of greenhouse gases in the atmosphere either by reducing their emissions or by increasing their capture.</td>
</tr>
<tr>
<td>Climate change scenario</td>
<td>A coherent and internally consistent description of the change in climate by a certain time in the future using a specific modeling technique and under specific assumptions about the growth of greenhouse gas and other emissions and about other factors that may influence climate in the future. A “climate change scenario” is the difference between a climate scenario and the current climate.</td>
</tr>
<tr>
<td>Climate change vulnerability assessment</td>
<td>A range of tools that exist to help communities understand the hazards that affect them and take appropriate measures to minimize their potential impact.</td>
</tr>
</tbody>
</table>

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| **Climate risk** | The likelihood that the harmful effects will happen, or a measure of the probability of harm to life, property, and the environment that would occur if a hazard took place. Risk can also be considered as the combination of an event, its likelihood, and its consequences, i.e., risk equals the probability of climate hazard multiplied by a given system’s vulnerability. |
| **Climate trend** | The general direction in which climate factors such as average annual temperature or rainfall tend to move over time. |
| **Climate variability** | Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. |
| **Concept of risk** | In the context of natural hazards, risk not only represents the possibility that a hazard event could occur but also its likelihood and consequences. There are many ways risk can impact a community—from the destruction of property and infrastructure, to injuries and casualties, and to influencing economic activity. As can be visualized by the figure on the left, the intersection of hazard, exposure, and vulnerability yields the risk (Reese and Schmidt, 2008). |

2 Niwa Taihoro Nukurangi. [Risk and Vulnerability](#).
MSRIP FIELD TRIP: 29 June–2 July 2019

1. 27 June 2019

Morning: Led by Mr. Shankar, EE PWD North, and Mr. D. Janak, Dy EE PWD North, the Maharashtra State Road Improvement Project (MSRIP) team conducted a round of consultations with three detailed design engineers: Mr. Akil Kumar, Mr. Amar Shirke, and Mr. Prafulla Patange.

   Agenda:
   (i) General discussions, state of condition of present road and bridges, exposure to natural hazards and sensitivities, general perspectives on climate resilience
   (ii) Hydrologic design, precipitation and data treatment, design discharges, floods, hydraulic structure types and structural dimensions
   (iii) Design temperature, pavement standards, asphalt bitumen specifications

Late afternoon: Proceeded to Ratnagiri by train.

2. 28 June 2019

Field visits: Project roads EPC-1(a) and (b), EPC-2(a) and (b) in Ratnagiri district accompanied by Mr. Sudhir Kamble, SE and Mr. M. Kadam, Dy EE.

Evening: Proceeded to Solapur by road.

3. 29 June 2019

Field visits: Project roads EPC-3(a) and (b), EPC-4(a) and (b) in Solapur district accompanied by Mr. R. Jatab, Engineer, Design Team, and Mr. A. Humdar, Dy EE, PWD Solapur.

Late evening: Proceeded to Pune by road accompanied by Mr. Jatab.

4. 30 June 2019

Proceeded by road to Mumbai.

5. 1 July 2019

Late morning: Wrap-up meeting with Joint Secretary Mr. Ingole and his deputies at MPWD Project Office.