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# Amaravati Building Climate Resilience

Report I May 2019

Clare Goodess, Colin Harpham, Nikki Kent, Ramesh Urlam,
Sushma Chaudhary, and Hem H. Dholakia


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Dr Colin Harpham provides inputs for major and minor projects on climate variability and change. His has primarily been technical inputs relating to the analysis of climate data. He is accustomed to dealing with large amounts of data in ASCII and binary formats - typically large gridded Net CDF datasets. He recently worked on the WHO-WELLCOME project (deriving indices and other statistics from CMIP5 global models and gridded observations) and the C3S ECEM project (processing historical data and downscaled projections) which has developed a pre-operational climate service for the European energy sector. Colin is a keen advocate of open source software which he uses wherever possible (e.g. Linux, R and GNU compilers).

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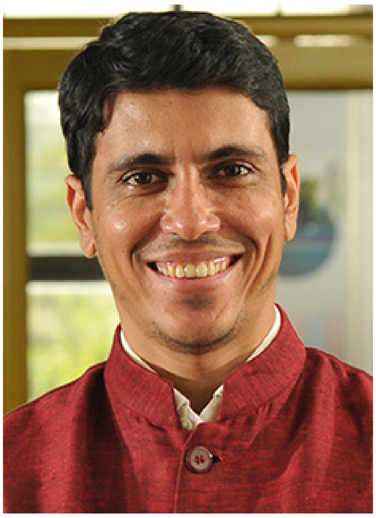
Sushma Chaudhary has a consolidated work experience of over 20 years as Infrastructure Specialist in the field of infrastructure projects. Being a Civil Engineer by qualification, and with post-graduation in Construction and Project Management, her core competence has been in multi-disciplinary large-scale infrastructure project planning and management. She has rich experience in project formulation, project planning and management, working with government and non-governmental organizations, procurement and contract management.

Committed to delivering resilient infrastructure, she has been actively engaged in assisting State Govts/ ULBs of select Indian cities to develop resilience frameworks, city development plans with focus on resilient infrastructure planning for multiple sectors- urban, transport, water and energy.



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Hem is a health professional turned policy researcher and leads the Risks and Adaptation portfolio for The Council. His research addresses the linkages between energy, environment, human health, and public policy in India. Specifically, it understands health impacts of urban air pollution, maps climate risks on infrastructure, develops early warning systems for extremes of heat and analyses potential of renewable energy to improve rural health outcomes.

Hem holds a PhD from the Indian Institute of Management (Ahmedabad); a Master's in Exercise Science from University of Brighton (UK,) and Bachelor's in Physiotherapy from Seth G.S. Medical College.

# Contents

# List of figures



# List of tables

# Abbreviations

| | |
|---|---|
| APCRDA | Andhra Pradesh Capital Region Development Authority |
| CDD | consecutive dry days |
| CORDEX | Coordinated Regional Climate Downscaling Experiment |
| cumecs | cubic metre per second |
| DCS | Distributed Control System |
| EIA | Environmental Impact Assessment |
| FCO | Foreign and Commonwealth Office |
| GCM | General Circulation Model |
| GFA | Gross Floor Area |
| GoAP | Government of Andhra Pradesh |
| GoI | Government of India |
| ICT | Information Control Technology |
| IITM | Indian institute of Tropical Meteorology |
| IRC | Indian Road Congress |
| km | kilometre |
| LED | Light Emitting Diode |
| MLD | millions of litres per day |
| MRT | Mass Rapid Transit |
| MSL | mean sea level |
| MW | mega watt |
| NMT | non-motorised transport |
| Ptotal | total rainfall |
| R20 mm | heavy-rainfall days |
| SCADA | Supervisory Control and Data Acquisition |
| STP | sewage treatment plant |
| TMC | thousand million cubic feet |
| Tmean | mean temperature |
| TN90p | warm nights |
| TX90p | warm days |
| UFW | unaccounted-for water |
| ULB | urban local bodies |
| WSDI | Heat-wave days (Warm Spell Duration Indicator) |
| WTP | water treatment plant |

The intensity and frequency of extreme weather events will increase under a changing climate.

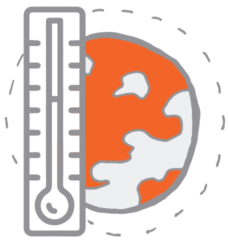
Image: iStock

# Executive Summary

Building cities requires large investments in infrastructure that encompass physical assets, functions, and systems. There is increasing recognition that infrastructure and related services are at risk due to climate change. Amaravati, being a greenfield city, presents an opportunity to plan infrastructure such that the impacts of future climate risks are mitigated.

**Amaravati needs to anticipate and prepare for a hotter and wetter future:** Data from climate models suggest that by the middle of the century, temperatures are likely to increase by about 1.8°C compared to current levels. Average rainfall is likely to increase by about 13 per cent by the end of the century. Days with extreme heat (i.e. heat-wave days) as well as heavy-precipitation events are likely to be more frequent. These changes may place infrastructure such as energy, transport, water supply, etc. at considerable risk.

**Opportunities exist to plan infrastructure such as energy, transport, and water supply that can withstand climate impacts:** A long lifetime and design and material considerations make infrastructure vulnerable. The potential impacts of climate change on infrastructure may include: compromised pavement integrity due to extreme heat; flooding risks due to overload of drainage systems; and fall in energy production as a result of extreme heat or water shortage. Further, the interconnected nature of infrastructure implies that interdependencies need to be mapped and addressed. Holding of regular risk assessments, adoption of better technical standards, use of resilient materials, and adoption of innovative financial instruments are some of the opportunities available to reduce vulnerability.



Data from climate models suggest that by the middle of the century, temperatures are likely to increase by about 1.8°C compared to current levels

**Financial impacts of climate risks on infrastructure may be considerable:** Although an assessment of the impacts on specific projects in these infrastructure sectors was beyond the scope of this study, it has been well established that climate change can have severe economic consequences. The current master plans for Amaravati indicate that the magnitude of investment across the energy sector is about INR 50,000 crore and that across the metro rail sector is about INR 6,700 crore. Significant investments will also be made in developing infrastructure for water supply, flood risk management, roads, telecommunications, housing, etc.

Typically, resilient infrastructure could cost up to 30 per cent more depending on the type of resilience measures being implemented. Further, it is important to cover residual risks arising from extreme events through suitable insurance mechanisms. It would be prudent to plan for these additional investments to protect infrastructure from the effects of climate change.

**Amaravati has commenced efforts to develop a climate-resilience roadmap.** A comprehensive climate roadmap involves five building blocks: (i) understanding how climate impacts Amaravati; (ii) scoping the city's objectives for managing climate-change impacts; (iii) defining the key climate risks faced by Amaravati; (iv) deciding strategies, plans, and designs to deliver optimal value; and (v) ensuring the implementation and monitoring of these plans. This framework can be tailored to the specific needs, objectives, and local contexts of Amaravati. The city has commenced work on some of these building blocks and is poised to build on these to ensure a climate-resilient future.

To make immediate progress, and to take advantage of the opportunity for Amaravati's development, it is recommended that Amaravati do the following:

i. Prioritise and undertake a climate-screening assessment of critical infrastructure such as energy, metro system, roads, and water supply

ii. Create plans based on trade-offs between system design after factoring in information on future climate trends and economic considerations

iii. Define the level of risk that the city is prepared to bear or the extent to which it is willing to build resilience and to implement resilience options that are appropriate to mitigate these risks

iv. Assign ownership and responsibility along with relevant timeframes for reporting progress in implementing resilience measures

v. Undertake periodic review and reporting of risks, resilience plans, and progress



The current master plans for Amaravati indicate that the magnitude of investment across the energy sector is about INR 50,000 crore and that across the metro rail sector is about INR 6,700 crore


Satellite map of Amaravati

*Source:*
*Google Mpas*

# 1. Introduction

India is currently undergoing rapid urbanisation. This transition is driven both by increases in population growth as well as migration from rural to urban areas. It is expected that by 2050 India will add another 300 million residents to urban areas. This would require large investment in urban infrastructure. It is estimated that over the next 20 years, investments of about USD 1 trillion are required for building urban infrastructure. Planning the cities of tomorrow will require meeting challenges such as inclusivity, governance, financing, and local capacity building. All these will be required to be situated in the context of a changing climate.

Today, there is unequivocal scientific evidence that climate change is being accelerated due to anthropogenic forces. The extent of future warming and associated impacts will be driven by global political choices. The associated risks and impacts of a changing climate will play out at the local level. These will be experienced as increased frequency and intensity of extreme events such as heat waves, flooding, and cyclones, as well as low-onset events like glacial melt and sea level rise. India remains vulnerable to all of these.

India is facing an increasing level and frequency of extreme-weather events and the impacts of climate change. Hence, governments at all levels (national, state, and local) and civil society are looking to mainstream climate resilience and emissions reduction into public policy.



More than 350 districts are expected to experience warming of more than 2°C by the end of the century

For instance, studies show substantial increases in both mean and extreme temperatures in India from 1950 to 2013. More than 350 districts are expected to experience warming of more than 2°C by the end of the century (Garg, Mishra, & Dholakia, 2015). Projected increases in precipitation may cause enormous damage to infrastructure such as bridges, roads, buildings, communication networks, and healthcare facilities. These are associated with impacts on lives and livelihoods, with far-reaching economic repercussions.
It is estimated that the annual direct costs of extreme events for India are in the range of USD 5-6 billion (Garg, Mishra and Dholakia, 2015). The associated economic costs could be significantly higher. Under scenarios where global temperature rise is not kept below 2°C, impacts and concomitant economic losses will increase in a non-linear fashion. More widely, city resilience to climate change is rapidly gaining pace as multi-country networks, international bodies, and donor organisations - such the Asian Cities Climate Change

Resilience Network,[1] 100 Resilient Cities,[2] and the C40 Cities Climate Leadership Group[3] - move to s support, collaborate, and exchange knowledge on how to increase city resilience to climate change.

While complementary support - in the form of policies, regulations, and improved building and infrastructure design codes that mandate designing for higher thresholds for temperature and precipitation - is needed at both national and state levels, there are actions that Indian cities are already taking to increase the resilience of their infrastructure to combat future climate change.

Preparing for, and investing in, building resilience will allow Indian cities to grow sustainably and to attract investment, companies, and skilled people, thereby gaining a competitive edge both nationally and internationally. Potentially nowhere else is this more realisable than in the case of the newly planned city of Amaravati, uniquely placing it as one of the first cities in India that is integrating climate resilience from the very outset of its development.

For greenfield cities such as Amaravati, this presents an opportunity to mainstream climate resilience into its city development plans. It allows for an opportunity to consider sectoral climate risks, their interaction, and their macroeconomic and distributional impacts, as well as to address institutional barriers in building adaptive capacity. In achieving these goals, it allows for setting up systems to capture relevant data, institute risk management processes, and design pertinent decision-making tools.

As a first step in mainstreaming climate change, this report assesses current and future climate transitions for Amaravati. It reviews city plans for various sectors such as transport, energy, and water to build a climate-resilience framework for Amaravati.



**Greenfield cities such as Amaravati have an opportunity to mainstream climate resilience into their city development plans**

1 https://www.acccrn.net/
2 http://www.100resilientcities.org/
3 http://www.c40.org/

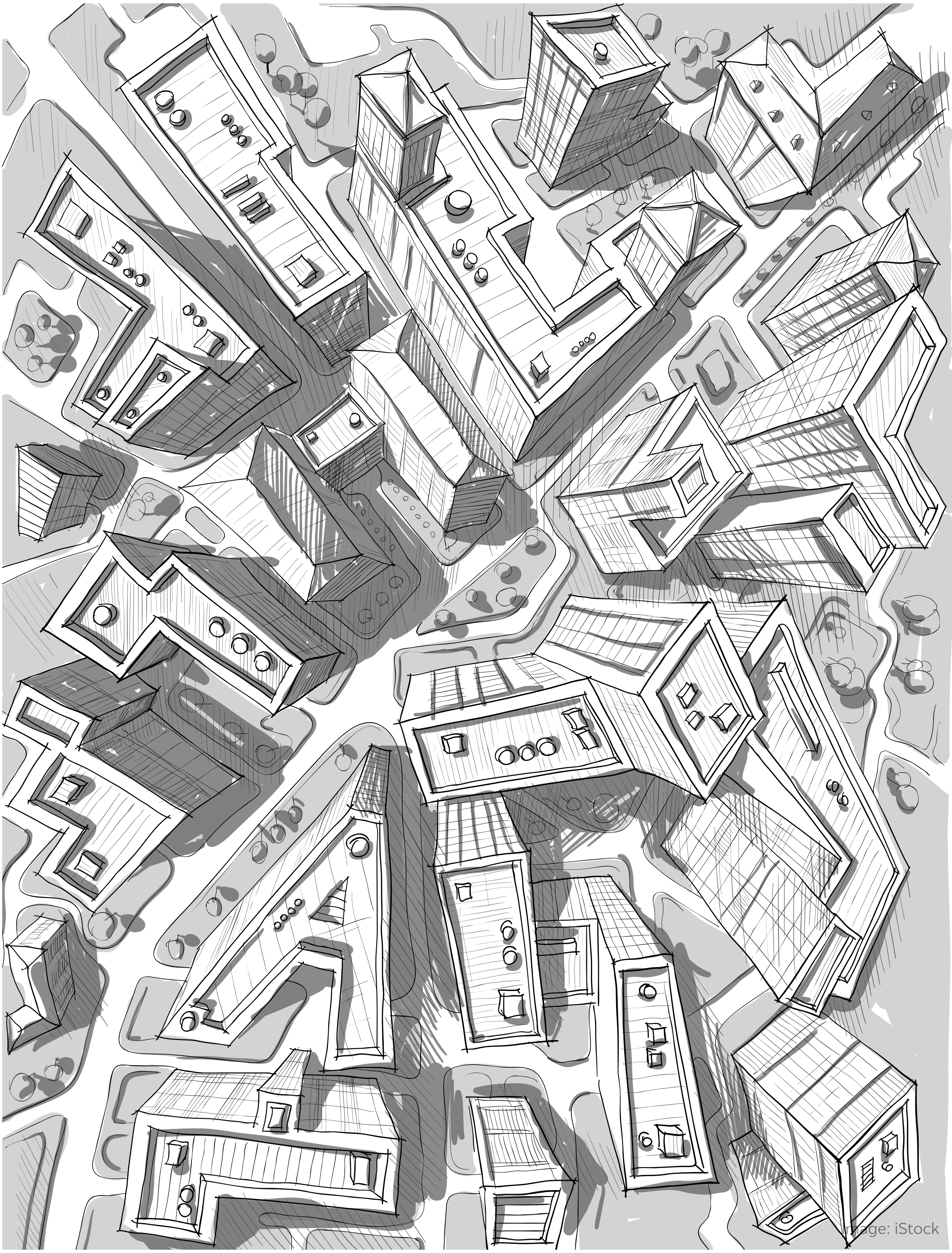


Image: iStock

A judicious selection of building materials and appropriate standards can help infrastructure adapt to higher temperatures.

Image: iStock

# 2. Methodology

## 2.1 Developing Amaravati's climate risk profile

To provide an overview for Amaravati stakeholders of the future climate risks faced by the city, as well as to provide a basis for the review of the sector master plan (Section C) and the climate resilience framework and roadmap (Section D) undertaken by other members of the project team, the first step was to produce a climate change risk profile for Amaravati. Since a major purpose of this profile was to promote awareness and to provoke thought and discussion among city stakeholders, it was agreed to produce this as a free-standing, relatively brief (four-page) document, written as far as possible in non-technical language to make it accessible to a broad audience. This risk profile (as provided to city stakeholders) is given in Appendix 1. It focuses on observed changes in and future projections of temperature and rainfall. Projections are provided for two emissions scenarios (Representative Concentration Pathways [RCPs]), which span the range considered in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

- RCP8.5: a high-end, 'business as usual' scenario
- RCP2.6: a low-end, mitigation scenario (consistent with the objective of the 2015
- Paris Agreement to keep global temperature change to 2°C or lower compared with pre-industrial conditions).

As described in the Appendix of the risk profile, the projections up to 2100 were constructed using output from CMIP5 global climate models (GCMs). Initially, 18-20 models (depending on the climate variable) were used; see Table 1.

3 WTO, *WTO Analytical Index Agreement on Safeguards - Article 1 (Jurisprudence)*, 2018

4 WTO, "Anti-dumping, subsidies, safeguards: contingencies, etc", https://www.wto.org/english/thewto_e/whatis_e/tif_e/agrm8_e.htm, Accessed on 20-11-2018

**TABLE 1:** List of available and excluded climate models

*Source: Authors' analysis*

| Global climate model acronym | Resolution (number of latitude x longitude cells) | Tmean | Ptotal | Indices of extremes | Model excluded in risk profile |
|---|---|---|---|---|---|
| CCSM4 | 192 x 288 | Y | Y | Y | |
| CNRM-CM5 | 128 x 256 | Y | Y | Y | |
| CSIRO-Mk3-6-0 | 96 x 192 | Y | Y | Y | X |
| CanESM2 | 64 x 128 | Y | Y | Y | |
| FGOALS-s2 | 108 x 128 | N | N | Y | |
| GFDL-CM3 | 90 x 144 | Y | Y | Y | |
| GFDL-ESM2G | 90 x 144 | Y | Y | Y | |
| GFDL-ESM2M | 90 x 144 | N | Y | Y | |
| HadGEM2-ES | 145 x 192 | Y | Y | Y | X |
| IPSL-CM5A-LR | 96 x 96 | Y | Y | Y | |
| IPSL-CM5A-MR | 143 x 144 | Y | Y | Y | |
| MIROC-ESM | 64 x 128 | Y | Y | Y | |
| MIROC-ESM-CHEM | 64 x 128 | Y | Y | Y | |
| MIROC5 | 128x256 | Y | Y | Y | |
| MPI-ESM-LR | 96 x 192 | Y | Y | Y | |
| MPI-ESM-MR | 96 x 192 | Y | Y | Y | |
| MRI-CGCM3 | 160 x 320 | Y | Y | Y | X |
| NorESM1-M | 96 x 144 | Y | Y | Y | |
| bcc-csm1-1 | 64 x 128 | Y | Y | Y | X |
| bcc-csm1-1-m | 160 x 320 | Y | Y | Y | |
| Total no. available | | 18 | 19 | 20 | |

Since the models all have somewhat different grid-box resolutions, all were interpolated to a standard 0.5 degree latitude-longitude grid, and the model output was extracted from the grid box in which Amaravati is located. This resolution was used to achieve consistency with the CRU-TSv.3.22 dataset (Harris, Jones, Osborn, & Lister, 2014). The latter dataset consists of gridded observations (based on thousands of quality-controlled and interpolated station time series) and was used to provide a like-with-like comparison with the model output over the historical period (1901-2013). For indices of extremes, another observed gridded dataset was used (Donat et al., 2013), which provides coverage from 1901 (or 1951 based on the specific model) to 2010, together with the processed CMIP5 model output (Sillmann, Kharin, Zhang, Zwiers, & Bronaugh, 2013a; Sillmann, Kharin, Zwiers, Zhang, & Bronaugh, 2013b).

Gridded observations were used to ensure consistency with the grid-box output of the climate models; in all cases, output was extracted for the grid box in which Amaravati is located. To indicate how these gridded observations relate to local conditions, annual and monthly station data from Machilipatnam/Franch (mean temperature) and Vijayawada (total rainfall) are also shown on some plots. These particular stations and variables were selected because they are readily available in the archives of the Climatic Research Unit. The Machilipatnam/Franch station was selected for data on temperature because it is the nearest station to Amaravati that was used in the construction of the relevant CRU-TSv.3.22 grid-box average. Details of the two stations are given in Table 2.

| | Mean temperature | Total rainfall |
|---|---|---|
| **Station name** | Machilipatnam/Franch | Vijayawada |
| **Years** | 1941-2016 | 1901-1970 |
| **Latitude/Longitude** | 16.20N 81.15E | 16.51N 80.61E |
| **Altitude** | 3 m | 20 m |

**TABLE 2:** Observed monthly/annual station data used in the climate risk profile

*Source: Authors' compilation*

Climate models are not perfect. Thus, a simple bias adjustment procedure was used to bring models and observations into line over the baseline period of 1961-1990. These adjustments were applied to the future on the assumption that the model errors were linear with climate change. Time series plots were produced to compare the observed and simulated data both before and after adjustment. The seasonal cycle of mean monthly temperature and rainfall was also compared over the baseline period of 1981-2010. For rainfall, these plots revealed four models that performed very poorly, with very low rainfall compared to observed data for the period and with no strong monsoon season (Figure 1, top). Applying the necessary adjustments to these models would mean artificially inflating their projected changes. Thus, these four models were excluded (see Table 1) and only the remaining models were adjusted (Figure 1, bottom) and used. Comparable plots for temperature are shown in Figure 2. Although the original 19 models simulate the seasonal temperature cycle reasonably well, to achieve consistency with rainfall, the same four models were excluded.

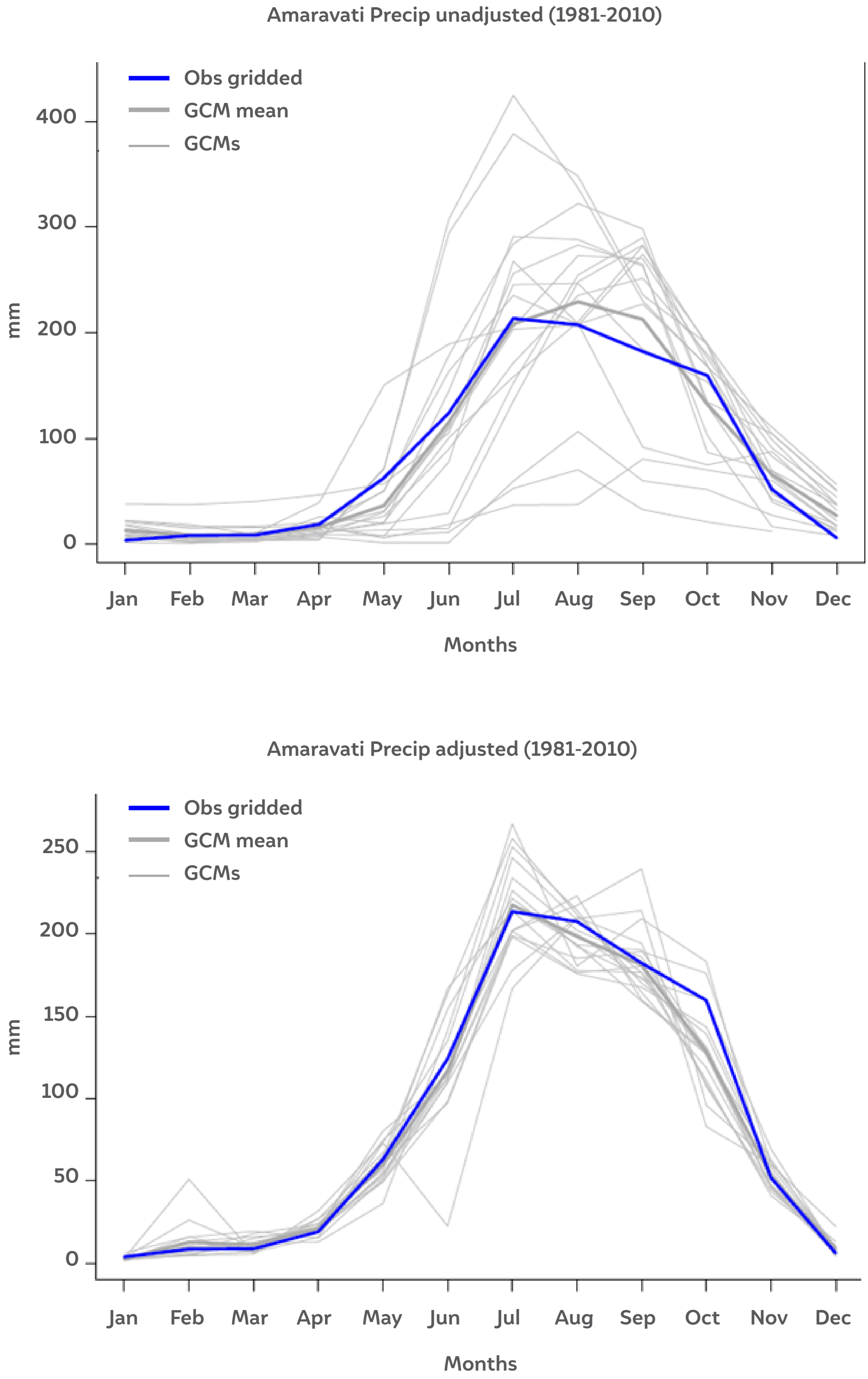
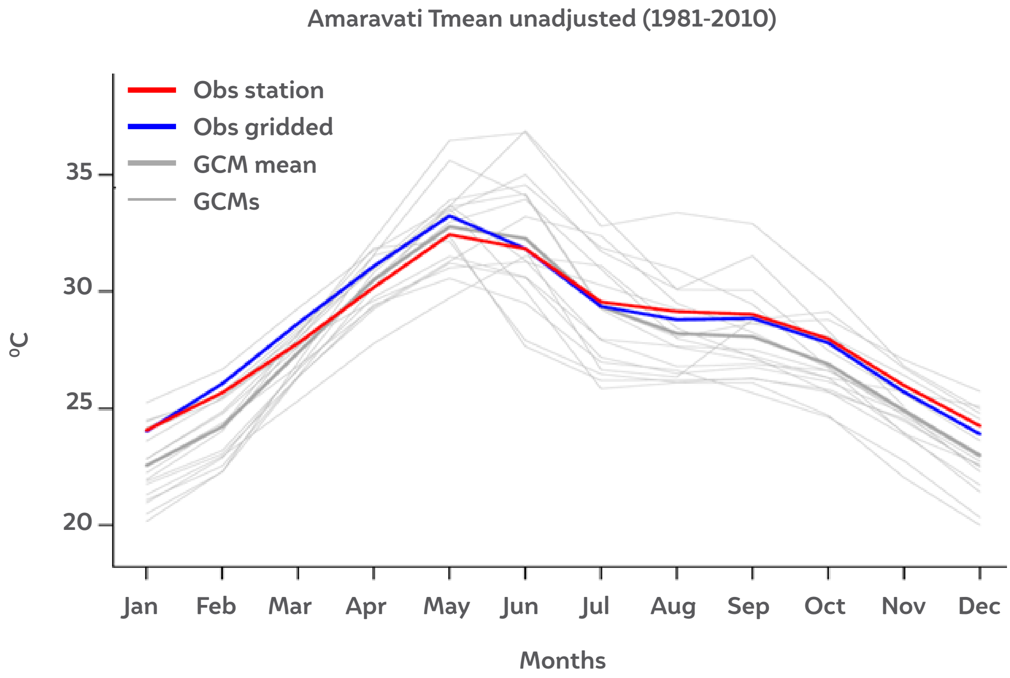



**FIGURE 1:**
Seasonal cycle of monthly gridded observed (blue) and simulated (grey) total rainfall for Amaravati for 1981-2010. Image (top): unadjusted output from 19 climate models. Image (bottom): adjusted output from 15 climate models.

*Source: Authors' analysis*



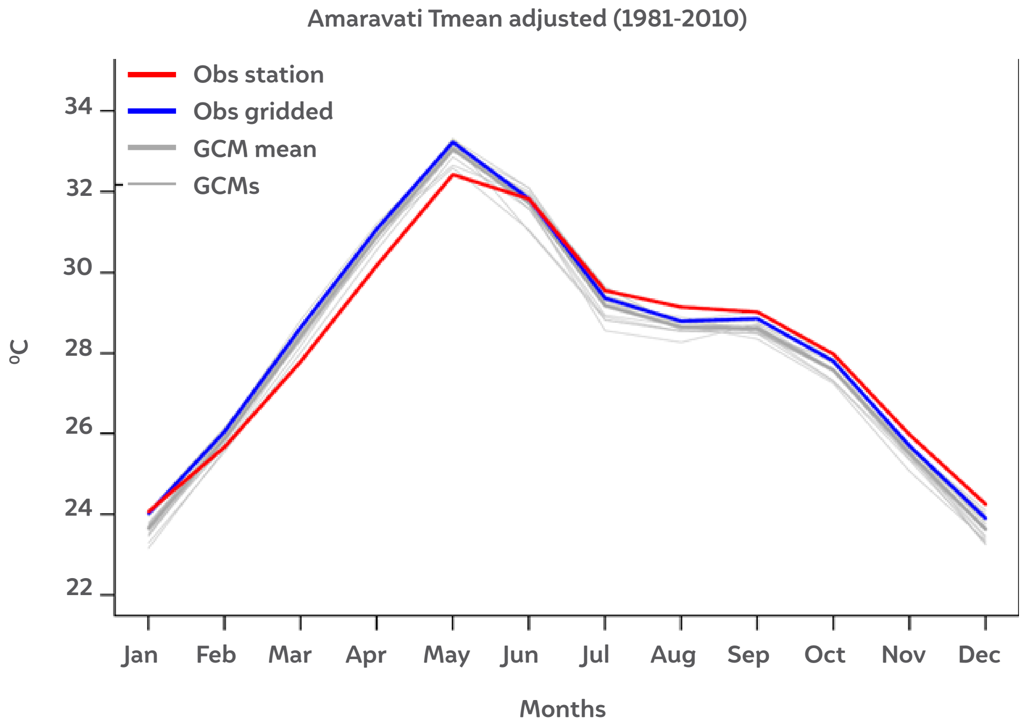




**FIGURE 2:**
Seasonal cycle of monthly observed station (red), observed gridded (blue), and simulated (grey) mean temperature for Amaravati for 1981-2010.

Image (top): unadjusted output from 18 climate models.

Image (bottom): adjusted output from 14 climate models.

*Source: Authors' analysis*

As noted above, time series plots were produced to compare the observed and simulated data both before and after adjustment. Plots for the ~15 selected models are shown in Figures 3 and 4 for the unadjusted and adjusted series respectively. In addition to the indices used in the risk profiles (see Table 2), these panels show a number of additional indices that were used to inform development plans and to check the profiles [Absolute Humidity (Abs Hum), Rain days > 10 mm (R10mm), Cold nights (TN10p), Cold Spell Duration (CSDI), Cold days (TX10p), and Rainfall from heavy events (R95p)].

Assessment of the unadjusted time series plots (Figure 3) indicates that the ~15 models simulate temperature extremes for the Amaravati region reasonably well, but tend to overestimate total rainfall and to underestimate dry spell length (CDD). Figure 4 shows that the simple bias adjustment used to bring models and observations into line over a baseline period of 1961-1990 is quite effective. For mean annual temperature, the adjustment factors required range from -0.2°C to +2.5°C across the models, with an average adjustment of +1°C. For total annual precipitation, ratios are used to make the adjustment, and range from 0.6 to 1.5, with an average value of 0.9 (indicating a 10 per cent overestimation on average by the models). The adjustment only affects the magnitude of the simulated values, not the trend - and it is evident that even before adjustment (Figure 3), the models are reasonably successful in capturing the direction of the trends observed over the historical period.

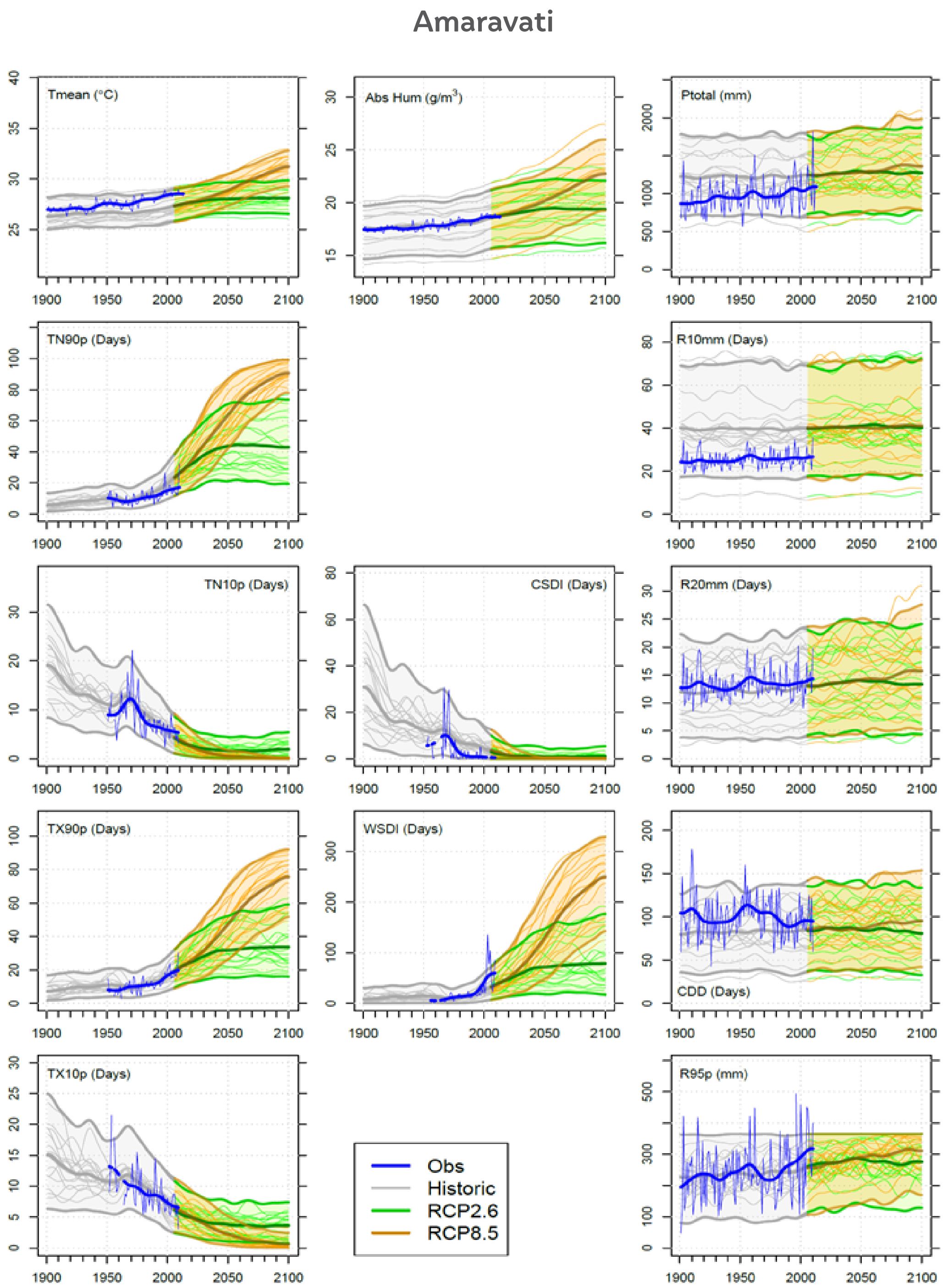



**FIGURE 3:**

Time series plot for 13 indices (see Table 3 and text) for Amaravati. Gridded observations are in blue. Unadjusted output from ~15 GCMs is in grey (historic period: 1901-2005), green (RCP2.6: 2006-2100), and orange (RCP8.5: 2006-2100). The ensemble average (thick lines), 90 per cent uncertainty range (shaded area), and individual models (thin lines) are shown.

*Source: Authors' analysis*

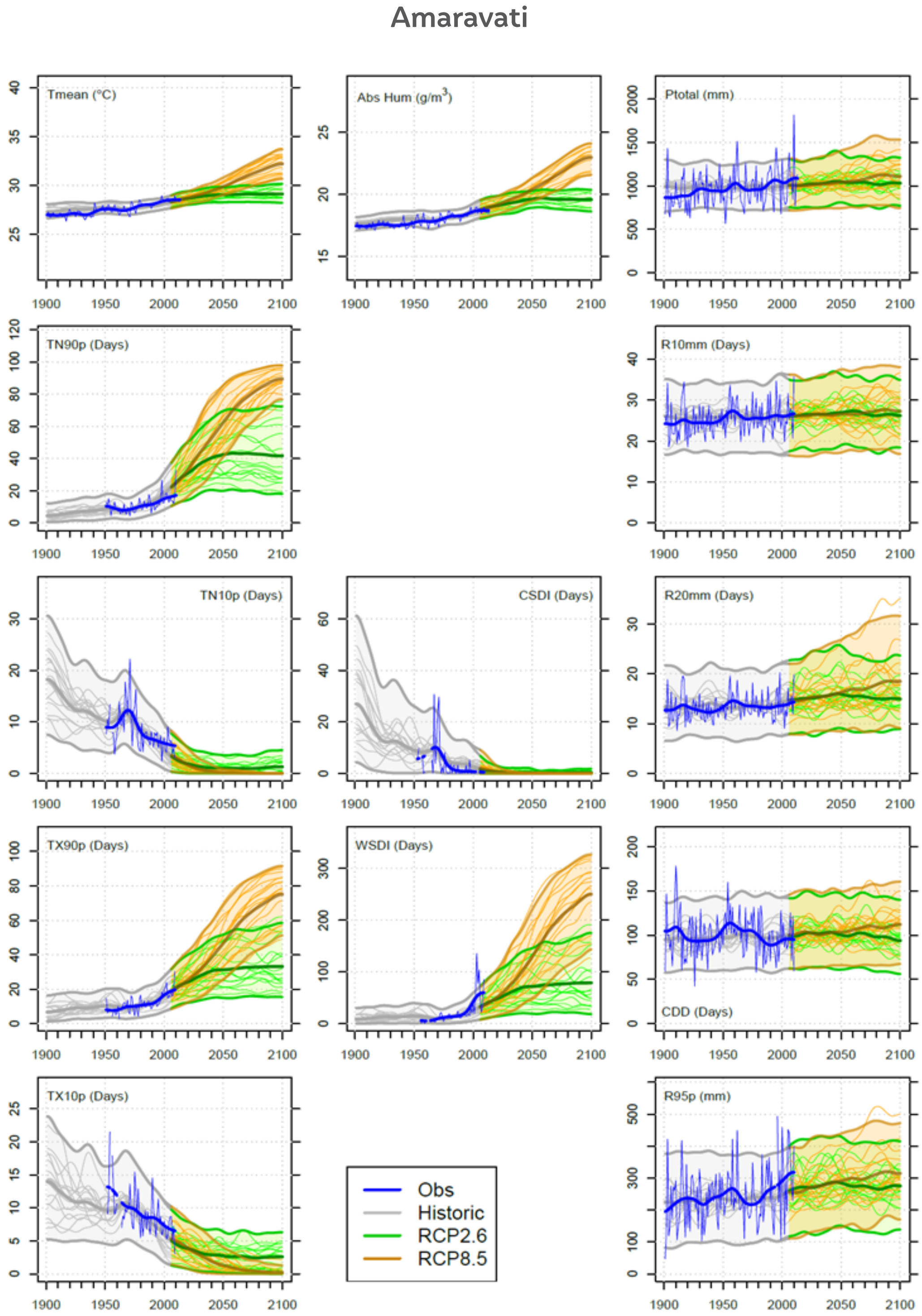



**FIGURE 4:**

Time series plot for 13 indices (see Table 3 and text) for Amaravati. Gridded observations are in blue. Adjusted output from ~15 GCMs is in grey (historic period: 1901-2005), green (RCP2.6: 2006-2100), and orange (RCP8.5: 2006-2100). The ensemble average (thick lines), 90 per cent uncertainty range (shaded area), and individual models (thin lines) are shown.

*Source: Authors' analysis*

Climate projections cannot be verified in the same way as a weather forecast or a seasonal forecast. Thus, agreement between observed and simulated values provides only a 'necessary but not sufficient' guide to the reliability of projections for the future. Confidence is generally higher in models that are able to reproduce present-day conditions, and particularly recent trends, but if, for example, a particular model is missing feedback that becomes more important in a warmer world, its projections may not be as reliable as implied by the comparison with observations. While further selection could be made on the basis of model performance, there is advantage in considering climate change across a larger ensemble. Thus, no further attempt has been made to select or rank models here.

The risk profile provides a summary of the observed and projected changes in both figure (time series) and table formats. Information is provided for both mean annual temperature and total annual rainfall, and also for a number of indices of extremes (Table 3). In order to provide an indication of the uncertainty range across the models, the 90 per cent uncertainty range (i.e. the range in which 90 per cent of the models lie) is shown as well as the ensemble mean (i.e. the multi-model average). Further, the risk profile lists:

- Key messages and implications for climate change risk assessment of the Amaravati development
- Potential impacts and risks associated with the key projected climate changes
- Issues requiring further investigation

| Index code | Descriptive name | Definition | Unit |
|---|---|---|---|
| **Tmean** | Mean temperature | Mean annual temperature | °C |
| **Ptotal** | Total rainfall | Annual precipitation total | Mm |
| **TN90p** | Warm nights | Number of days when TN > $90^{th}$ percentile | Day |
| **TX90p** | Warm days | Number of days when TX > $90^{th}$ percentile | Day |
| **WSDI** | Heat-wave days (Warm Spell Duration Indicator) | Annual count of days with at least 6 consecutive days when TX > $90^{th}$ percentile | Day |
| **R20 mm** | Heavy-rainfall days | Annual count of days when precipitation ≥ 20 mm | Day |
| **CDD** | Consecutive dry days | Maximum number of consecutive days with no precipitation (precipitation < 1 mm) | Day |

**TABLE 3:**
Definitions of climate indices, including indices of extremes, used in the climate change risk profile. TN: minimum temperature. TX: maximum temperature.

*Source: Authors' analysis*

Finally, Appendix A provides information about the construction of the projections, highlighting issues relating to model reliability and projection uncertainty since these are important considerations when interpreting and using the information provided.
One of the identified issues requiring further investigation relates to the spatial scale of the projections presented in the risk profile. They are based on global climate model output at a relatively coarse spatial scale. Table 1 gives the number of latitude x longitude cells for each model, while the HadEX2 observed dataset has a spatial resolution (before interpolation) of 2.5 degrees latitude by 3.75 degrees longitude. This rather coarse resolution is likely to

be an issue when considering the intensity of extremes such as maximum daily rainfall; such values are inherently lower when computed as area averages (as is the case for model grid boxes) rather than point values. Thus, for detailed hydrological modelling, it would be worthwhile exploring the use of dynamically downscaled regional climate model output. In particular, it is recommended that output from the international CORDEX coordinated regional modelling initiative should be used or worked with (https://www.cordex.org/).

CORDEX output, including daily precipitation, is available for a South Asia domain with a grid-box resolution of 50 km. See http://cccr.tropmet.res.in/home/cordexsa_datasets.jsp for further information and data links. In particular, a reasonable number of simulations are available from the RegCM4 model run by IITM, India and from the RCA4 model run by SMHI, Sweden. Each of these regional models has been forced by six different GCMs. All of these global models (except EC-EARTH, which was not available, and CSIRO-Mk3.6, which was excluded due to its poor rainfall cycle) are used in preparing the Amaravati risk profile. Thus, the data presented here would provide a useful context for exploring the potential added value of the downscaled data, as well as analysing a wider uncertainty range. An alternative approach would be to use some sort of statistical downscaling such as a weather generator, but the advantage of dynamical downscaling is that it provides physically consistent information across both space and variables. Whichever approach is taken, reliable daily observations would be required for model validation and calibration.

## 2.2 Connecting the climate risk profile to the city development plans

Following initial discussions with Amaravati city development officials to identify their key concerns about climate risks for Indian cities, and a review of the climate data compiled in the Amaravati City Climate Risk Profile on observed changes and future projections of temperature and rainfall (Appendix A), a review of the city master plans and documentation related to a selection of important sectors (transport infrastructure, water supply infrastructure, energy demand, and flood management) was conducted. These reviews undertook an initial climate-screening assessment based on the available literature and city-related documentation. The sector reviews:

- looked at how the projected changes in temperature and rainfall could impact the sectors in question and their development plans
- focused on a series of key climate considerations for Amaravati in the context of its status as a newly planned city
- compiled and identified relevant sector-specific resilience recommendations in a roadmap ranging over different timescales where possible

The main climate considerations for the development of Amaravati city in conducting an initial review of the masterplans focused on identifying infrastructural components that could potentially be impacted by the projected increase in temperature and rainfall. The following sets of questions were posed in carrying out the analysis:

### 2.1.1 New climate data considerations

- Has the anticipated change in the amount or range of precipitation and temperature actually taken place? Have you already seen extreme events that are reaching these thresholds?

### 2.1.2 Infrastructure considerations

- Identify planned aspects or components of infrastructure that could potentially be affected by the temperature and rainfall change thresholds projected for the city. Remember that as far as temperature is concerned,the urban heat island affect could increase this further.

- Identify the percentage of green and blue spaces in the planned city development. Can these spaces be increased, linked up, and redesigned to have multiple benefits (e.g. surface water storage, cooler shaded outside space, recreation)?

- Identify the flood return period used for the planned infrastructure and determine its relevance.

- Identify hotspots - areas where critical energy, water, and transport infrastructure is going to be located - that may be more at risk from climate change.

- Identify low- or no-regret resilience options that are reliable and efficient, as well as allow maximum flexibility in the planning stage. These options can cover aspects of design, technical, engineering, policy, regulation, and capacity building, for different categories of infrastructure components and materials.

Reservoir planning and management will be critical to tackle future inundation of the city.

Image: iStock

# 3. Review of Amaravati's development plans

This section provides a review of the current masterplans across four key sectors - transport, water, energy, and flood management. For each sector, we consider the proposed design and potential risks associated with climate change. Based on an assessment of future climate risks, resilience options are proposed.

## 3.1 Transportation

Transport is an essential urban service for any city. A key aim of transportation planning is to facilitate mobility of people and goods,with the aim of providing access to employment, education, health, and recreation. A well-thought-out transportation plan could be leveraged for furthering economic development and for improving the quality of life Draft of study prepared by blue consultants Tata-Arcadis citizens. Therefore, transportation systems form the backbone of provision of goods and services to citizens.

The traffic and transportation plan for Amaravati was formulated to provide seamless,safe, and convenient universal access to employment, housing, and amenities through sustainable public transit and non-motorised transportation systems. To achieve this goal, the Transport Master Plan (TMP) for Amaravati provides a broad idea of future transport systems and transport infrastructure that could be adopted in the city, along with connectivity between the city and the surrounding areas as well as connectivity with different parts of the country.

### 3.1.1 Current situation

A key driver of transportation planning for Amaravati has been future population projections. By 2050, Amaravati's population is expected to reach 3.58 million. Of these, 2.1 million people will be actively employed across different professions. To cater to the mobility demand of this population, the TMP for Amaravati has laid out a series of road networks for inter- as well as intra-city mobility.

The region of the planned new city of Amaravati is served by five national highways. The internal network of the city is laid out in a grid pattern with four main categories of roads following well-assigned roles of access and mobility through a hierarchical system. The perspective plan of the capital region has already identified one inner ring road and one outer ring road to allow transit through traffic, which at present passes through the city of Vijayawada. The Rights of Way (ROWs) of the roads identified in the Concept Plan are given below:

1. Major arterial roads: 60m ROW with 8-lane configuration and 52 km
2. Arterial roads: 50m ROW with 6-lane configuration and 91 km
3. Seed access roads: 60m ROW with 4-lane configuration and 18m mass transport corridor in median and 19 km
4. Sub-arterial roads: 50m ROW with 4-lane configuration and 18m mass transport corridor in median and 154 km
5. Collector roads: 25m ROW with 4-lane divided configuration and 277 km

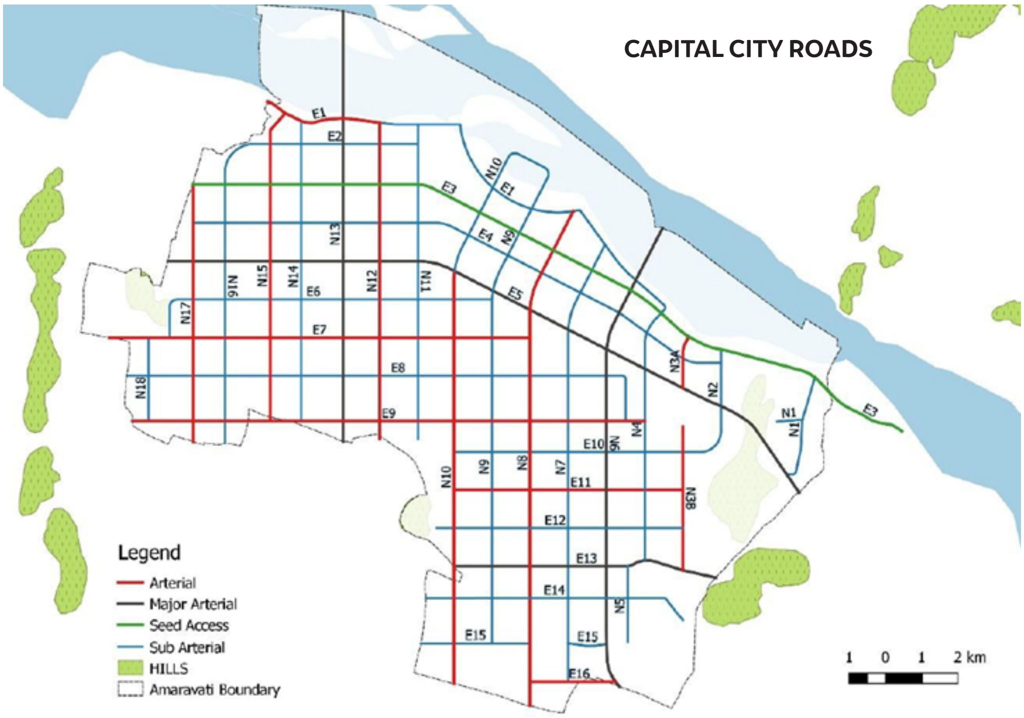



**FIGURE 5:** Higher-order road network

*Source: Amaravati Draft Traffic and Transport Plan*

In addition to the road network, an integrated multimodal mass transport system with reliable and efficient last-mile connectivity has been conceptualised for Amaravati city. The phased development of the passenger transport (PT) network involves (1) expansion; and (2) transition from a lower- capacity PT system to a higher-capacity one (Figure 6).

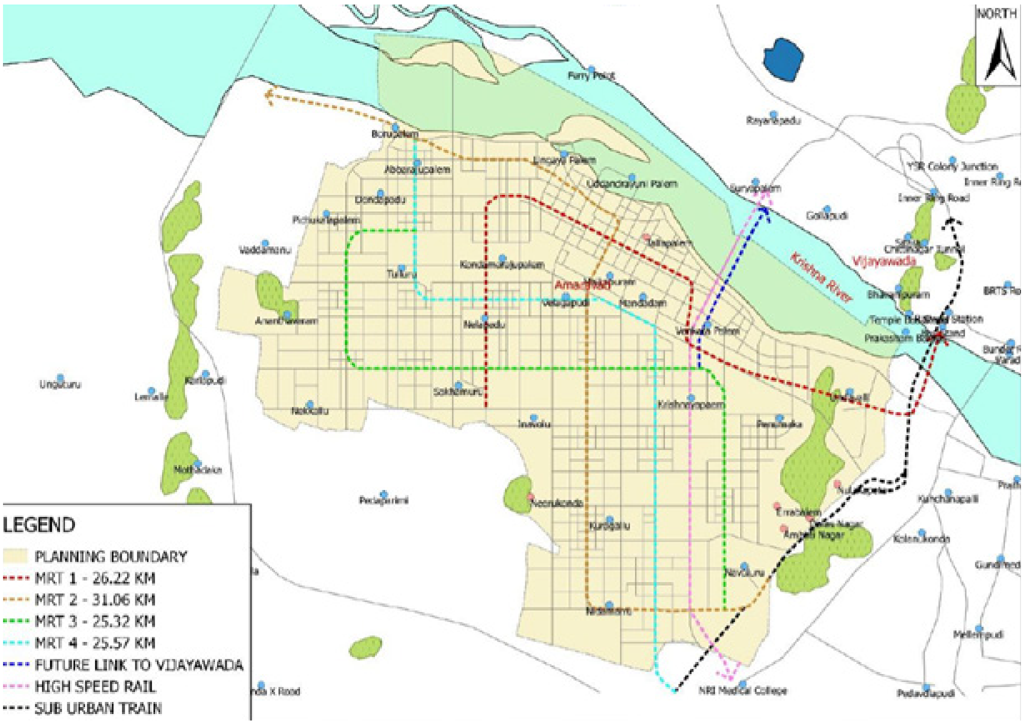



**FIGURE 6:**
Proposed MRT Lines

*Source:*
*Amaravati Draft Traffic and Transport Plan*

The Transport Master Plan envisages a rapid transit system with public transport accounting for an ultimate share of 70 per cent by 2050, with the same being 80% in the central business district (CBD). It proposes to introduce bus rapid transit (BRT) as the core transit system, which in later years may need to be upgraded to a metro/mass rapid transit (MRT) system in response to growth in travel demand levels. A mass transport system is proposed along four routes and a future second extension is proposed to the west side of Vijayawada. The extension of mass transport corridors to Guntur and to present-day Amaravati town is also envisaged in the Master Plan. A total of 15 depots for a fleet of 1,500 urban buses and about 500 midi-size buses shall be developed across the city. About 22 intra-city bus terminals supported by 15 depots shall cater to PT-based demand. (Table 4).

| Year | Distribution of Passenger Trips Generated due to Amaravati - One-way trips | | | | Total Daily One-way Trips |
|---|---|---|---|---|---|
| | I-I | I-E | E-I | E-E | |
| **2019-20** | 112,500 | 37,500 | 257,143 | 21,429 | 428,571 |
| **2025-26** | 412,500 | 137,500 | 392,857 | 39,286 | 982,143 |
| **2035-36** | 1,120,000 | 280,000 | 486,111 | 58,333 | 1,944,444 |
| **2050-51** | 3,108,832 | 444,119 | 710,590 | 248,707 | 4,512,247 |

**TABLE 4:** Distribution of one-way trips

*Source: Amaravati Draft Traffic and Transport Plan*

| Year | Intra-city Bus Terminal | Inter-city Bus Terminal | Mass Transport Station | Regional Railway Station | High-Speed Rail Station | Airport |
|---|---|---|---|---|---|---|
| **2019-20** | 45,000 | 81,214 | - | 78,113 | - | 2,995 |
| **2025-26** | 132,000 | 133,837 | 112,406 | 69,673 | 29,847 | 8,397 |
| **2035-36** | 276,640 | 181,864 | 267,880 | 106,451 | 60,614 | 11,262 |
| **2050-51** | 598,450 | 332,565 | 681,456 | 243,741 | 129,727 | 16,148 |

**TABLE 5:** Number of daily one-way trips at public transit nodes of Amaravati

*Source: Amaravati Draft Traffic and Transport Plan*

Supporting infrastructure for non-motorised and pedestrian transport has also been planned. These modes will be integrated with a network of e-rickshaws to provide last-mile connectivity for areas located away from mass transport nodes.

The current Master Plan is more focused on the physical infrastructural requirements for the city. We recommend that the following policies and guidelines be undertaken during the course of implementation:

- Parking policy
- Street design guidelines
- Non-motorised transport policy
- Transit Oriented Development plan with guidelines
- Information technology supported traffic demand management

Although the master plan discusses the concept of utility corridors, the particulars have not been detailed out. The common utility duct is a structure, generally located below ground that carries more than two types of public utility lines such as power cables, telephone lines, or water pipelines. The advantages of the common utility duct are reduction of the number of maintenance manholes, one-time relocation, and less excavation and repair compared to separate cable ducts for each service. Such ducts are well mapped and allow rapid access to all utilities without having to dig access trenches. It is recommended that all major arterial roads, arterial roads, seed access roads, and sub-arterial roads in Amaravati. The city should be built with utility corridors, including the provision for future expansion.

### 3.1.2 Climate change risks for transportation sector

Climate change can be manifested through gradual changes in climate parameters (e.g. rainfall, temperature) or through an increased frequency of extreme events. Transportation systems are vulnerable to both types of changes. Steady increases in temperature, changing groundwater levels, and solar radiation have an effect on the durability and functioning of road infrastructure. Higher temperatures may lead to the development of cracks in road surfaces. Increased precipitation can result in the formation of potholes or in the deepening of existing ones. All these impacts shorten the durability or longevity of road surfaces, leading to higher operation and maintenance costs. Further, indirect consequences such as accidents, decrease in travel speed, or vehicular congestion could have far-reaching economic implications. Extreme-climate events may result in destruction of roads, damage to culverts, as well as collapse of bridges. These disruptions are likely to restrict access to healthcare services and impede emergency response systems, potentially threatening human and even animal life.

Therefore, system-wide resilience and sustainability planning should be considered at an early stage during the decision-making process. This is particularly important given the long lifecycle of transport infrastructure investments. Further, early intervention allows for consideration of options and priorities for transportation investments to meet multiple community goals in the face of changing climate. The development of a climate-resilient transportation system requires a holistic solution that will cover the development and implementation of technologies, the management of resilience measures, as well as the specification and introduction of technical regulations. Figure 7 sets out the broad direction, indicative measures, and suggested sequence of resilience recommendations.

**Development and implementation of methodologies**

- Analysis of vulnerability of road network and detection of potential affected road network elements.
- Estimation of economic costs of adaptation measures. Consider the cost of disruption due to extreme weather events versus the cost of adaption.

**Development and application of technologies**

- Resilient drainage systems, soil strengthening and rock stabilization techniques, and early warning systems.
- Resilient asphalt and concrete pavements (mixture and pavement design, paving technologies) and methods of increasing skid resistance.
- Resilient, long life and low maintenance new bridges and adaptation measures for increasing resilience of existing bridges, pre emptive protection systems for tunnel structures against flooding and solutions for conservation of groundwater reserve during tunnel construction and operation.
- Rapid and automated inspection and survey methods as well as sustainable maintenance measures and techniques.

**Development and introduction of management and resilience measures**

- Models to forecast weather events, congestion, other relevant factors and real time management systems to provide early warning of trigger events and instigate intelligent re routing and modal shift. Development of guidelines to cope with restricted flow, or re-routing during extreme weather events.
- Development and implementation of adaptation options and resilience measures and techniques for new and existing road network infrastructure.

**FIGURE 7:** Broad resilience recommendations for the transport sector[4]

*Source: Authors' compilation*

4 European Roadmap, Climate Resilient Road Transport, Version May 20, 2011.

### 3.1.3 Roadmap for transport infrastructure: Recommendations for increasing Amaravati's climate resilience

The purpose of this roadmap is to examine the potential impacts on transport infrastructure and to identify the adaptation measures that may be required.

Some infrastructure in Amaravati that could be at risk from climate change is listed below:

1. **Rise in asphalt temperature may compromise pavement integrity** (e.g., softening asphalt and increasing rutting from traffic): 593 km of the main road network of Amaravati will be affected, the high-capacity inner ring road and the outer ring road are more vulnerable, and this will have a greater impact on operations in case of failure.

2. **Thermal expansion of bridge joints** will adversely affect bridge operation and increase maintenance costs. Linkages (road and rail) across the Krishna River will be affected.

3. **Increased risk of flooding** may damage roads and affect roadway, railway, and Mass Rapid Transit (MRT) lines close to the Krishna River.

4. **Drainage systems are likely to be overloaded** more frequently and more severely, causing backups and street flooding, especially in low-lying areas of the city

5. **Effects of storm surge/wave action** will cause more frequent interruptions in the working of the inland waterway system planned in Amaravati city.

Given the long planning horizons for transport infrastructure, it is important to determine whether, when, and where the long-term impacts of climate change could be consequential.

Resilience measures are identified for the transport sector to reduce losses and risks in the event of significant changes in temperature and extreme rainfall:

- Using heat-resilient paving materials
- Using heat-reflective paint on footpaths
- Building heat-tolerant streets and adopting measures for landscape protection
- Designing infrastructure for withstanding higher maximum temperatures
- Upgrading road drainage systems
- Grooving and sloping pavements
- Raising the standard for drainage capacity
- Issuing more warnings and providing updates to dispatch centres, crews, and stations

### 3.1.4 Design considerations under conditions of increasing temperature

Given the projections of an increase in the average temperature for Amaravati, it is recommended that this factor be incorporated into all future design to ensure the durability and robustness of the new infrastructure.

For pavement design, mainly selected on the basis of the Proposed Traffic option, temperature is an additional consideration that will impact the top bituminous layers of the pavement structure. The effect of temperature on the bituminous layers of pavement composition can be seen from Clause 7.4 and Table 7.1 of the Indian Road Congress (IRC) Code number IRC 37:2012 (page 74), which is used for the flexible pavement design of Indian projects. The following extracts from the IRC may be used for the designing of pavements:

| Maximum average air temperature | Traffic | Bituminous course* | Grade of bitumen to be used |
|---|---|---|---|
| ≤ 30°C | ≤ 1500 commercial vehicles per day | BD, DBM and BC | VG 10/ VG 20 |
| < 40°C | For all types of traffic | BM, DBM, SDBC and BC | VG 30 |
| ≥ 40°C | Heavy loads, expressways | DBM, SDBC, BC | VG 40 bitumen for wearing course as well as binder course. Modified bitumen |

**TABLE 6:**
Selection of binder for Bituminous Mixes

**DBM: Dense Bituminous Layer; BM: Bituminous Macadam; BC: Bituminous Concrete; SDBC - Semi-dense Bituminous Concrete; BD: Bituminous Dressing*

*Source:*
*Indian Road Congress (2012)*

Rise in temperature affects bridges to a certain degree. Reinforced Cement Concrete (RCC) and pre-stressed concrete bridges are more resilient to climate change than steel bridges. For the design of any future bridge, please refer to IRC (2014), which gives guidance on design considerations for bridges according to the maximum and minimum temperatures expected at the location of the bridge.

## 3.2 Water supply

Human life is contingent upon access to potable water. A reliable, efficient, and clean water supply system is necessary for the social, economic, and environmental well-being of Amaravati City. The water supply master plan for the city provides the blueprint of the water infrastructure needs and planning, assessment of the source and quantum, and guidelines for the development of associated infrastructure like trunk main, distribution system, treatment units and Information control technology (ICT) controls.

Under a changing climate, it is no longer sufficient for the city to look at asset creation in isolation. Adaptation should be integral to the creation and maintenance of all new assets in the city, enabling resilience and operational efficiency, safeguarding public service and safety, and minimising economic loss.

The purpose of this sector review on water infrastructure is to draw the attention of city policy makers and of infrastructure owners, operators, and investors to climate vulnerability and risk profiling. Further, we highlight multi-level gaps in water infrastructure and urban governance, and emphasise the need to integrate climate change with long-term plans for development of and investment in strategic infrastructure. This approach helps protect against acute events (that may be occurring already), as well as prepare for the added impact of events in the future.

### 3.2.1 Current situation

The Master Plan proposes to integrate the development of the capital city with the development of the existing villages. At present, most of the existing villages in the project area are dependent on groundwater sources. The groundwater contains metals like sodium, magnesium, and iron. At present, chlorination is the only process being undertaking to produce potable water.

Based on the projected population for 2050, the total clear water demand and the total raw water demand are estimated to be at 752 MLD and 776 MLD (10 TMC), respectively, for the design period of 2050 for a total project area of 217 sq km (Table 7). The rates of water supply established for different service categories have been established keeping in mind standards of the Central Public Health and Environmental Engineering Organisation manual, Central Ground Water Board, the Urban Development Plan Formulation & Implementation guidelines, as well as international best practices.

| Design Year | Residential Population | Workforce (Commercial/ Institutional/ Industrial) | Residential Water Demand @ 165 LPCD | Workforce (Commercial/ Institutional) Water Demand @ 49.50 LPCD | Industrial Water Demand @38,500 KL/ Day | Total Water Demand, including UFW@10%, Trans mission Loss@2% | Total Water Demand, including Treatment Loss@3% | Raw Water Demand (TMC) |
|---|---|---|---|---|---|---|---|---|
| 2020 | 428,747 | 141,618 | 70.74 | 5.50 | 9.07 | 95.73 | 99.00 | 1.28 |
| 2025 | 892,951 | 294,949 | 147.34 | 12.34 | 13.61 | 194.43 | 202.00 | 2.61 |
| 2030 | 1,219,776 | 402,902 | 201.26 | 16.93 | 18.15 | 265.18 | 275.00 | 3.55 |
| 2035 | 1,707,387 | 563,964 | 281.72 | 24.40 | 21.17 | 367.23 | 380.00 | 4.90 |
| 2040 | 2,570,405 | 849,025 | 424.12 | 38.01 | 24.20 | 545.66 | 563.00 | 7.26 |
| 2045 | 3,237,778 | 1,069,464 | 534.23 | 48.42 | 27.22 | 684.28 | 707.00 | 9.12 |
| 2050 | 3,552,950 | 1,173,568 | 586.24 | 53.07 | 30.25 | 752.00 | 776.00 | 10.00 |

**TABLE 7:** Estimated water demand for Amaravati

*Source: Amaravati Master Plan on Water Supply*

For the new capital city, 24x7 potable water supply infrastructure is being planned to meet the projected dramatic increase in water demand. The present supply - on the basis of which the existing village schemes are functioning - will not be able to cater to the future demand of Amaravati. Further,the existing infrastructure is inadequate to sustain the water demand of the new capital city. It has been planned that the water requirement for Amaravati will be met from the Krishna River and its tributaries. To meet the requisite water demand of 10 TMC, the master plan recommends the combination of two sources, i.e. 1.0 to 1.5 TMC water from the existing Prakasam Barrage and the balance water from the proposed Vaikuntapuram Barrage, both of which are in the vicinity of the project site. However, if for some reason the Vaikuntapuram Barrage is not constructed, the water will be drawn from the Pulichintala Dam, located at a distance of 70 km from the project site. Source sustainability is the major factor that will influence the project design and proposals. Availability of water will be contingent on the specific allocation to Amaravati city. This would require regulation by the Government of Andhra Pradesh.

Another site-related constraint is that the terrain of the project area is too flat for the construction of pipeline distribution networks. This will increase the requirement of reservoirs/pump stations. In addition, as the soil is mostly silty clay,the selection of appropriate material for pipes will be essential to ensure the longevity of the piped infrastructure.

From the climate perspective, changes in rainfall intensity can affect source sustainability, and average warming can result in increased water use requirements, with an impact on water infrastructure. The potential climate risks to water security are shown in Table 8. Rise in temperature and changes in precipitation pattern can have clear implications for water security and could also lead to drought, or excessive rainfall could result in flash flooding. Hence, it is important to assess the impact and its likelihood and to plan for resilient infrastructure.

The present supply - on the basis of which the existing village schemes are functioning - will not be able to cater to the future demand of Amaravati

**TABLE 8:** Possible climate risks to water security and reliability

*Source: Authors' analysis*

| Projected climate changes | Potential impacts and risks |
|---|---|
| Warmer conditions, including more intense and frequent high-temperature extremes and heat waves | • Reduced yields due to decline in quantity of water (due to low flows, increased evaporation, and drop in water quality)<br>• Unsustainable demand for water services, resulting in increased risks of water shortages<br>• Increased energy consumption for operation of water infrastructure<br>• Potential increase in demand for air conditioning/cooling, resulting in increased consumption of water and energy<br>• Human heat stress and other negative health effects, including potential increases in mortality, particularly if water turbidity increases and water quality decreases<br>• Negative impacts on labour productivity, particularly on outdoor construction workers<br>• Extreme condition of heatwaves and drought |
| Higher annual rainfall totals and more frequent/ heavy-rainfall events | • Potential increase in flood risks/flash floods because storage reservoirs and city drainage infrastructure are not planned to accommodate these extreme events<br>• Sewer flooding caused by rainfall, thereby overwhelming sewer capacity<br>• Possible implications for water balance and for the quantity and quality of water resources (also taking into consideration long dry spells and increased evaporation in warmer conditions |

### 3.2.2 Climate change impacts on water and water supply for Amaravati

The climate of the Amaravati region is tropical, with extremely hot summers and pleasant winters, and is monsoon dependent. Summer usually lasts from March to June, with the temperature ranging from 30°C to 48°C. Future projections of temperature for Amaravati city over the horizon of the next 33 years show an upward trend of mean annual temperature as well as increased infrequency of temperature extremes. Under a high-emissions scenario, Amaravati could experience an increase of 3.7°C in mean annual temperature by the end of the century (2071-2100).

This temperature rise could result in higher precipitation losses as well as increased water consumption and increased stress on energy requirements for operating the water infrastructure. The expected rise in temperature for Amaravati by 2050 is an increase of 1.8°C in mean temperature with a corresponding increase of 32 warm days and 46 warm nights. Also, the average annual rainfall trend reflects a clearer tendency towards more intense and more frequent rainfall extremes.

Only a few studies have attempted to quantify the influence of climate change-related factors on water use in urban cities that could be benchmarked. Nevertheless, climate impacts are seen in many extreme events across the globe, thereby emphasising the urgent need to increase awareness about this issue and to plan for climate resilience. The creation of sustainable sources of water and prudent demand management will be important for building resilience of water systems to climate risks.

### 3.2.3 Road map for water and water supply infrastructure: Recommendations for increasing Amaravati's climate resilience

The Amaravati resilience road map for water supply (Table 9) is based on the following recommendations for initiating and sustaining a climate change resilience plan. The approach to resilience includes:

- Addressing current risks and vulnerabilities
- Creating awareness about climate risks and generating demand: Bottom-up approach
- Demonstrating resilience projects to generate interest among urban local bodies (ULBs) and other decision-makers
- Generating information on multiple sectors and on the shelf of project proposals
- Building sustainability-related aspects into planning (demand management and green infrastructure)
- Building synergy with state and national institutions

As Amaravati is being planned as a new city on a greenfield site, there is an opportunity to develop new facilities with due consideration for resilience to climate change and to build weather effects into the planning and permitting processes such that most climate change effects can be mitigated. The key recommendations for climate-resilient water supply are divided into two categories, that is, at the planning or policy level and at the implementation level. See Annexures B and C for further details on the benefits of green infrastructure and the benefits of water demand management as part of an adaptation or resilience plan.

**TABLE 9:** Recommendations for water and water supply

*Source: Authors' compilation*

| Short-term | Mid/Long-term | |
|---|---|---|
| Planning/Policy-Level Recommendations | Operational-Level Recommendations | Implementation Level - Capital/ Infrastructure Recommendations |
| **Assessment of Source Certainty**<br>» Most future requirement is planned to be met from the proposed Polavaram and Vaikuntapuram barrage projects. As both surface and subsurface water is being used, adequate storage capacity of reservoirs should be assessed and dependability should be established for the required quantity of water. Finalise the source of water supply, with firm allocation of water needs being made by GoAP.<br>» Use hydraulic models to project runoff and incorporate results in water supply planning.<br>**Govt. policies should assist in adapting infrastructure to climate-change impacts**<br>» Formulate state water policy and create institutional framework structure for the same to ensure O&M strategies and good governance for water supply infrastructure.<br>» Applicants for new water resources/water utility infrastructure (with more the 20+ years of design life) (dams/reservoirs) should consider the impacts of climate change in planning the location, design, building, operation, and decommissioning of such infrastructure.<br>» New policies and stronger, coordinated | **Dual Water Supply Network**<br>» Finance and facilitate systems to recycle water, including use of grey water, in homes and businesses, with potential use for flushing, gardening, cleaning, etc.<br>**UFW Reduction Programme**<br>» Practise water conservation and demand management through water metering, leak-detection and water-loss monitoring, rebates for water-conserving appliances/ toilets and for rainwater-harvesting tanks.<br>» Check distribution of water from supply end to user end; develop water audit system, supported by information technology (dedicated software). Implement metering system for industrial and residential areas. Ensure that bulk consumers also monitor UFW.<br>» Conduct regular leak assessment, detection integration with SCADA, and removal of the same so as to reduce UFW to below 10% level.<br>» Account for losses in the supply system through the application of ICT linked with the central command and control centre through which the entire system of flow distribution will be monitored, controlled, and operated.<br>**Equitable Distribution of Water Supply**<br>» Begin pressure monitoring at important points. Map the entire water distribution network. | **Reservoir Management System**<br>» Increase water storage capacity, including through silt removal, of existing reservoirs; construct new reservoirs and/ or dams.<br>» Retrofit intakes to accommodate lower water levels in reservoirs.<br>**Waste-to-Energy System**<br>» Build systems to recycle waste water for energy, industrial, household, and agriculture use.<br>» Divide command area of reservoir into District Metered Area so as to control the quantity of water distributed in the area.<br>**Promotion of Green Infrastructure**<br>» Implement green infrastructure on site by improving stability and permeability of soil at facilities and in public areas (including green roofs, filter strips, and more permeable building materials) to reduce runoff and associated pollutant loads into the storm water collection system and into surface water bodies.<br>» Build new storm water retention structures (e.g., rain gardens/ponds) as a part of the planned improvements to the collection system in service area.<br>» Construct service roads, footpaths, and parking lots with permeable surfaces.<br>**Implement source-control measures at treatment plants** to deal with altered influent flow and quality at treatment plants. |

**TABLE 9** contd

| Short-term | Mid/Long-term | |
|---|---|---|
| Planning/Policy-Level Recommendations | Operational-Level Recommendations | Implementation Level - Capital/ Infrastructure Recommendations |
| cross-sector effort are needed to deliver more ambitious reductions in water consumption; new water-supply infrastructure should be planned strategically along with balancing interdependencies across sectors<br><br>» Formulate policy on restriction of the overexploitation of groundwater resources with support from Central Ground Water Board (CGWB).<br><br>**Development of a Comprehensive Water Demand Management Plan by Municipal Corporation**<br><br>» Water-efficiency and conservation practices should be inbuilt both at the supply side (related to the drinking water utility's actions to increase the efficiency of water delivery to consumers) and at the demand side (related to the customer's actions to reduce the usage of water in homes and businesses).<br><br>» Ensure that planned infrastructure is resilient to potential increase in the frequency and intensity of acute-weather events and that this is accounted for in the investment decisions.<br><br>» Conduct training for personnel on climate-change impacts and adaptation. | Set up a control room to monitor those areas that are experiencing reduction in pressure.<br><br>» Set up adequate numbers of active maintenance teams and prioritise zero-tolerance monitoring system using technological support (e.g. Geographical Information System).<br><br>**Focus on development of groundwater and rainwater-harvesting systems**<br><br>» The open space/area proposed in the planned area should have facilities for rainwater harvesting and the intermediate zones should be recharged. Similarly, the recharge area of confined aquifers should also not be urbanised or unnecessarily paved.<br><br>» Encourage development of groundwater resources at community level rather than at individual level (community bore well supply).<br><br>**Water User Groups**<br><br>» Create urban water user groups for conjunctive water management of local and distant water resources with focus on building resilience to climate change.<br><br>**Manage reservoir water quality**<br><br>» Invest in practices like lake aeration to minimise algal blooms due to high temperature. | **Build or expand infrastructure to support conjunctive use.**<br><br>**Establish alternative power supplies,** potentially through on-site generation, to support operations in case of loss of power.<br><br>**Plan treatment capabilities addressing changes in water quality** (e.g. increased turbidity or **salinity)**<br><br>**Set aside land** to support future flood-proofing needs.<br><br>**Schedule structuring and phasing** with development plan for proper linking of project proposals phase-wise |

**TABLE 9 contd**

| Short-term | Mid/Long-term | |
|---|---|---|
| Planning/Policy-Level Recommendations | Operational-Level Recommendations | Implementation Level - Capital/ Infrastructure Recommendations |
| **Development of Alternatives for Water**<br>» Ensure efficient implementation of rainwater-harvesting systems at community and household levels to increase groundwater potential and recharge capacity.<br>» Set up a dedicated workforce to focus on exploring technological options for wastewater recycling and reuse options at community level by adopting internationally recognised practices<br>» Develop and implement pilot projects on various alternative methods of water usage in the city. Assess details of such examples and share results in open domains to win the confidence of the public.<br>» Conduct public awareness-raising programmes on the economics of water through IEC. Ensure mass awareness on importance of water conservation and reduction of water wastage at household level.<br>**Practise Leadership**<br>» The ULB should take the lead in setting the example of conjunctive water management practices at institutional level and their transfer to community level | | |

## 3.2 Energy sector

Energy is well recognised as a core driver of development. A Master Plan to provide 24*7 power has been drawn up for Amaravati. This Master Plan lays down a set of guiding principles and a framework for the planning and prioritisation of current and future initiatives in the power sector. The Master Plan presents the anticipated power demand, based on which a detailed plan involving various elements of the power supply, transmission, and distribution infrastructure has been prepared. The Master Plan also provides a blueprint for the quantum of power planned from various types of generation sources as well as transmission lines and substations that would be needed to distribute the electricity. Amaravati will use a mix of fossil fuel and renewable energy sources to achieve cleaner power and a lower carbon footprint. We review the assumptions for power demand as well as the potential risks of climate change on energy consumption for Amaravati.

### 3.3.1 Current situation

The Master Plan document for energy has estimated the power requirements based on demand factors, land use area, and gross floor area (GFA) of the proposed development (Table 10). Since all electrical equipment are not used simultaneously, a diversity factor is also taken into consideration. The demand factors have been defined based on the typical demand in developed countries across different land-use patterns. This approach often results in conservative estimates of energy demand.

| Classification | Standards watt/sqm | Diversity factor |
|---|---|---|
| Residential (R1-R4) | 22-37 | 0.3-0.5 |
| Commercial | 30-50 | 05-0.6 |
| Industrial (I1-I3) | 35, 45, & 60 | 0.4 |
| Government/Institutional (S1-S3) | 30-35 | 0.5 |
| Parks and open spaces (P1-P2) | 5.0 | 0.4 |
| Utilities (U1-U2) | 1.5 | 0.4 |

**TABLE 10:** Power demand standards based on usage type

*Source: Energy Master Plan for Amaravati*

The Master Plan has assumed that energy demand is directly proportional to the built-up area. As per the Master Plan, classification of area utilisation is considered (Table 11). Based on the area of each classification, the built-up area is arrived at by duly considering ground coverage, net floor coverage, and floor area ratio for all utilities. LED lighting fixtures are considered to minimise the lighting demand. District cooling system is considered only for government buildings. Power demand is assessed across the Amaravati capital region.

| Classification | Power demand (MW) |
|---|---|
| Residential | 999.52 |
| Commercial | 667.96 |
| Government / Institutional | 190.84 |
| Industrial | 553.00 |
| Parks and open spaces | 32.02 |
| Roads | 17.22 |
| Residential area in commercial and industrial zones | 46.29 |
| WTP and STP | 30.00 |
| DCS system | 40.00 |
| Line losses @4.79% | 129.65 |
| **Grand Total** | **2,706** |

**TABLE 11:**
Estimated power demand across different usage type

*Source:*
*Energy Master Plan for Amaravati*

The built-up area, in turn, depends on the projected population of the capital region. The estimated power demand is based on the built-up area for a projected population of 3.58 million upto 2050. The power density is found to be 12.47 MW/sq km. This power density is higher compared with other international cities (Table 12).

| | Description | Tianjin Eco City in Singapore | New York | Tokyo | Toronto | Amaravati |
|---|---|---|---|---|---|---|
| 1 | Area in sqkm | 34 | 789 | 8,547 | 630 | 217 |
| 2 | Estimated/Existing Peak load in KW | 411 | 5,160 | 64,300 | 5,000 | 2,706 |
| 3 | Peak load MW/sqkm | 12 | 7 | 8 | 8 | 12 |

**TABLE 12:**
Power demand across international smart cities

*Source:*
*Author's analysis*

The initial power demand assessed was 2,706 MW by the Amaravati Capital Region Development Authority. The power requirement for the start-up area was estimated to be 270 MW. However, the Singapore Consortium has estimated a higher power requirement of 860 MW for the start-up area. Considering this higher requirement, the total power demand for Amaravati has been estimated at 3,325.65 MW (including transmission losses at 4.79 per cent). Thus, the total power demand till 2050 for Amaravati has been assessed at 3,326 MW for a total area of 217 sq. km (Table 13).

| | Details | Power demand (MW) |
|---|---|---|
| 1 | Power demand for capital city as per population details collected from APCRDA | 2,576.35 |
| 2 | Additional power demand for start-up area as specified | 590.00 |
| 3 | Total power demand for capital city | 3,166.35 |
| 4 | Transmission loss @ 4.79% | 159.30 |
| 5 | Total power demand for capital city | 3,325.65 |

**TABLE 13:**
Total power demand as per the suomotu proposal for the start-up area

*Source:*
*Energy Master Plan for Amaravati*

### 3.3.2 An alternative approach to estimating Amaravati's power requirement

The above-mentioned power demand estimates are based on the specific power demand of the built-up area as per land use. To validate this estimate, another approach was adopted for demand assessment considering per capita electricity consumption.

As Amaravati is a greenfield city, there are no baseline data on per capita electricity consumption that can be extrapolated for the future. Hence, the per capita consumption of Vijayawada (which is 60 km from Amaravati and has similar weather) was used as the baseline. It was assumed that power requirements would escalate, with an annual growth rate of 6 per cent till 2050. This figure of a 6% growth rate was arrived at based on India's per capita electricity consumption.

India's per capita electricity consumption has been increasing steadily over the years. It rose from 734 kWh in 2008-09 to 1,075 kWh in 2015-16, an increase of 46 per cent in eight years. This implies an average increase of six percent per year for the above time-period. It crossed 1,000 kWh in 2014-15 for the first time. The highest increase in per capita consumption during these eight years was in 2011-12 when it grew by almost 8 per cent (Figure 8 and Annexure E).

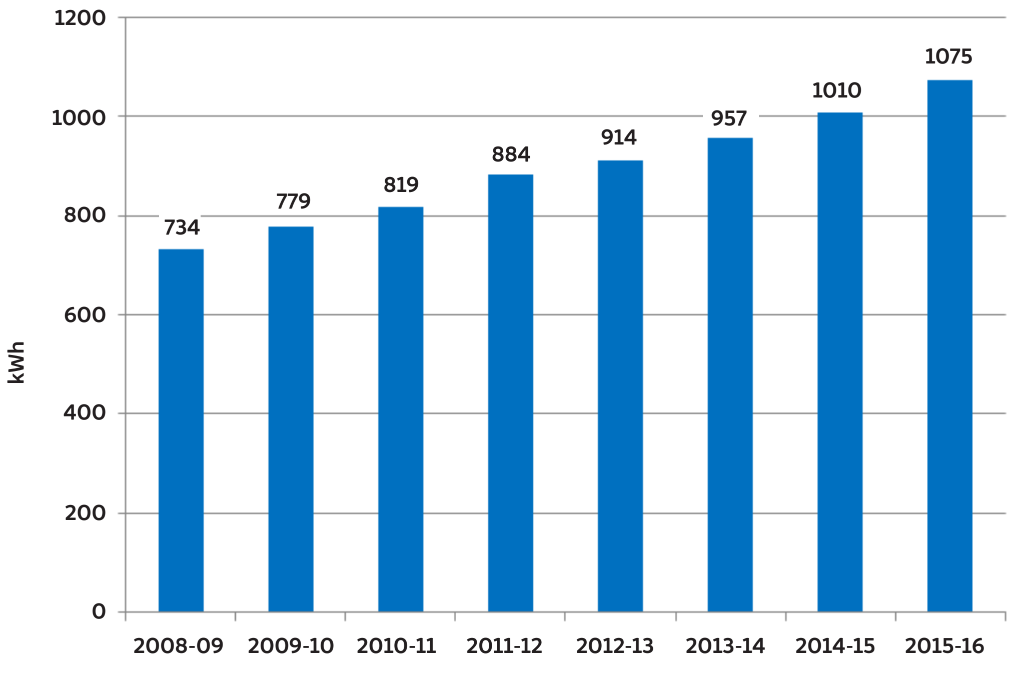



**FIGURE 8:** Per capita electricity consumption in India

*Source: Central Electricity Authority (compiled from various reports)*

The electricity consumption data for Vijayawada are given in Annexure D. As per the data, the current annual electricity consumption for Vijayawada is 1,141.5 million KWhr (for an estimated population of 1.27 million in 2016). Vijayawada's current population was estimated based on a population of 1.05 million as per Census 2011. This translates to a per capita electricity consumption of 902 KWhr for 2016 for Vijayawada. Taking the baseline of per capita electricity consumption as 902 KWhr, and considering an annual growth rate of

6 per cent, the per capita electricity consumption for 2050 works out to 6,540 KWhr. For a population of 3.58 million, this translates to an electricity demand of 23,415 million KWhr. With a 70 per cent plant load factor, this translates to a peak demand of 3,818 MW.

### 3.3.3 Observations on power demand assessment in the Master Plan document and that derived from per capita electricity consumption data

The power demand assessment of 3,326 MW by 2050 estimated in the Master Plan is based on the assumption of specific power consumption per m2 for different consumer segments and the planned built-up area for different categories of consumers. Since Amaravati is a greenfield city, such an approach provides a logical basis for power demand assessment for 2050. The power demand assessment considering the per capita electricity consumption is based on the premise that there will be a steady 6 per cent year-on-year growth in electricity demand. This difference leads to a 15 per cent variance in the predicted power demand in 2050.

While a 6 per cent growth rate had been the trend in the past, more recent trends indicate that power demand has increased at a slower rate, leading to a power-surplus situation. If the power demand growth rate were to drop to 4 per cent after 2030, power demand (as assessed by the per capita approach) will drop to 2,608 MW.

### 3.3.4 Impacts of electrification of transport sector

The Government of India (GoI) has initiated policies to boost the share of electric vehicles (EV) in the transport mix. Under the National Electric Mobility Mission Plan, a target of six to seven million EVs by 2020 has been set. The intent is to reduce oil imports, particulate emissions, and GHG emissions. It is expected that initially conventional sources of power will fuel the transition to EV. However, a combination of solar power and EV is expected to provide a long-term sustainable transportation option.

It is difficult to estimate the likely increase in electricity demand due to the transition to EV because this is closely tied to the rate of decrease in battery prices. The price of the lithium ion battery has been dropping steadily and by 2025 is expected to reach USD 150/KWhr, which would make it affordable. Competitive pricing is likely to encourage a rapid shift to EVs and they may constitute 60 per cent of the vehicle fleet by 2050. For instance, for a fleet of 3,000 electric buses, the additional power demand for charging would be about 90 MW. However, if most of these vehicles were to charge their batteries at night, significant amounts of additional power generation capacity may not be required.

### 3.3.5 Climate change impacts on energy demand for amaravati

Climate change has clear implications for energy production and consumption. For instance, a rise in mean annual temperature can be expected to increase energy requirements for space cooling and to reduce energy requirements for warming. Further, high temperatures could impact the efficiency of thermal power plants. Changes in precipitation could affect the prospects for hydropower, positively or negatively. Concerns about climate change impacts could change perceptions and valuations of energy technology alternatives. Any or all of these types of effects could have an impact on the power infrastructure.

Of the different climate parameters, electricity demand is most responsive to changes in temperature. This has clear implications for energy production and consumption. For instance, average warming can be expected to increase energy requirements for cooling, water pumping, etc.

The climate change impact on temperature in Amaravati for 2050 is a 1.8°C increase in mean temperature with a corresponding increase of 32 warm days and 46 warm nights.

There are only a few studies in India that provide an estimate of the increase in electricity consumption with an increase in ambient temperature. The studies carried out in the United States have estimated a 5 per cent increase in electricity demand for a 1°C increase in temperature for Florida. This implies that Amaravati would need to anticipate and plan for higher electricity demand in the future, well over above current estimations. This could be achieved through a priori implementation of energy-efficiency standards, adoption of demand-side management measures, and installation of additional generation capacity.

## 3.4 Flood management

Flood management plans for Amaravati were reviewed based on the Environmental Impact Assessment (EIA) plan, the Master Plan, and the Seed Development Area Plan. The Andhra Pradesh Capital Region Development Authority has engaged consultants to prepare the 'blue study' that is expected to be the basis for the design of the city's water reservoirs and to develop flood management/mitigation plans, urban waterways, and a canal system in a manner that makes them safe, clean, and aesthetically pleasing. However, these reports emanating from the blue study/plans were not available to the current study for review. Nevertheless, based on the available reports and plans on flood management and the review undertaken, the following inferences were drawn.

### 3.4.1 Current situation

The Environment Impact Assessment report and the Capital Seed Development Master Plan report envisage flood management as part of the resource management system integrated with infrastructural development. The details of the reports on flood management are described briefly here.

1. One of the boundaries of the proposed city of Amaravati is along the southern bank of the Krishna, a major interstate river, with a barrage (Prakasam) near the capital city. An existing bund along the Krishna currently protects the capital city area from the high water levels of the river. The bund levels along the capital boundary range from +25 m to +27m above MSL.

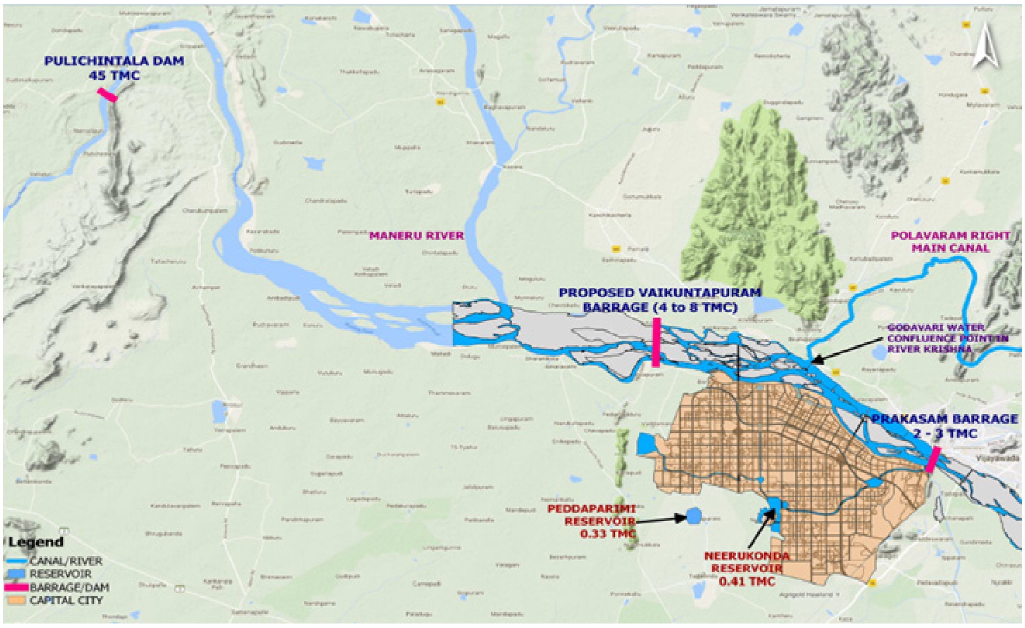



**FIGURE 9:** Proposed Capital City Area along the bank of the Krishna River and the Prakasam Barrage

*Source:*
*Draft Seed Development Plan for Amaravati*

2 The capital city area suffers annual inundation due to flu vial flow from the Krishna River and runoff from the Kondaveeti Vagu, a major drain flowing through the capital city area. This drain, with a catchment area of 421 sqkm under its sub-tributaries, overflows every year during the monsoon, inundating about 13,500 acres of the capital city area.

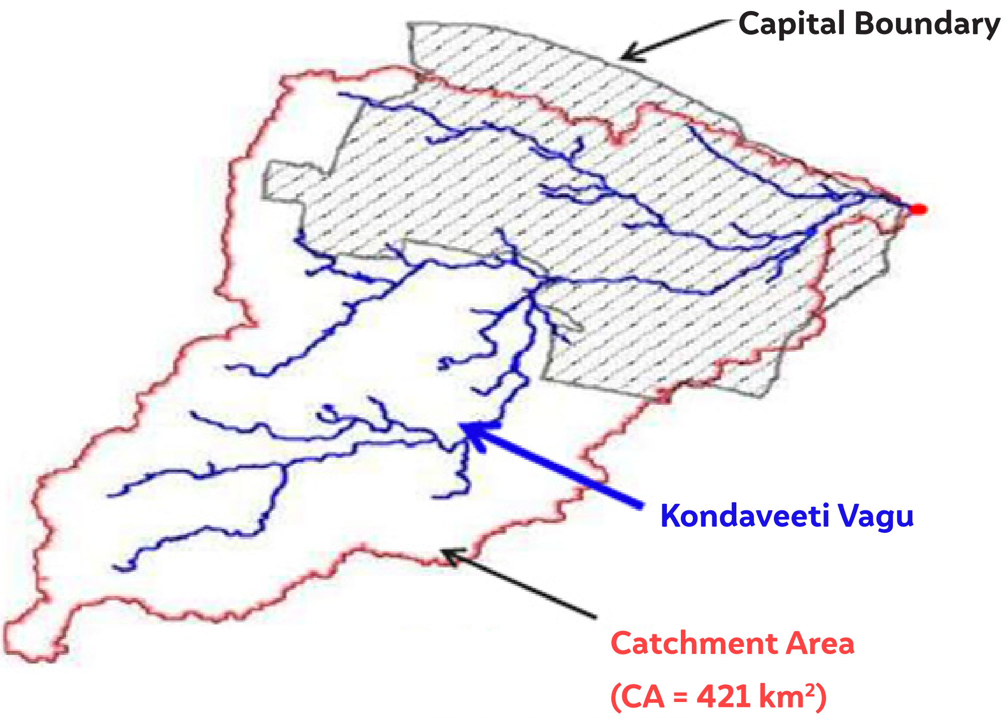



**FIGURE 10:** Catchment area of Kondaveeti Vagu and the capital city area

*Source:*
*Draft Seed Development Plan for Amaravati*

3 A rainfall of 222 mm in 24 hours for a 100-year return period flood has been predicted by the blue consultants, Tata-Arcadis, based on a consideration of historical rainfall data and the results of hydrological and hydraulic modelling.

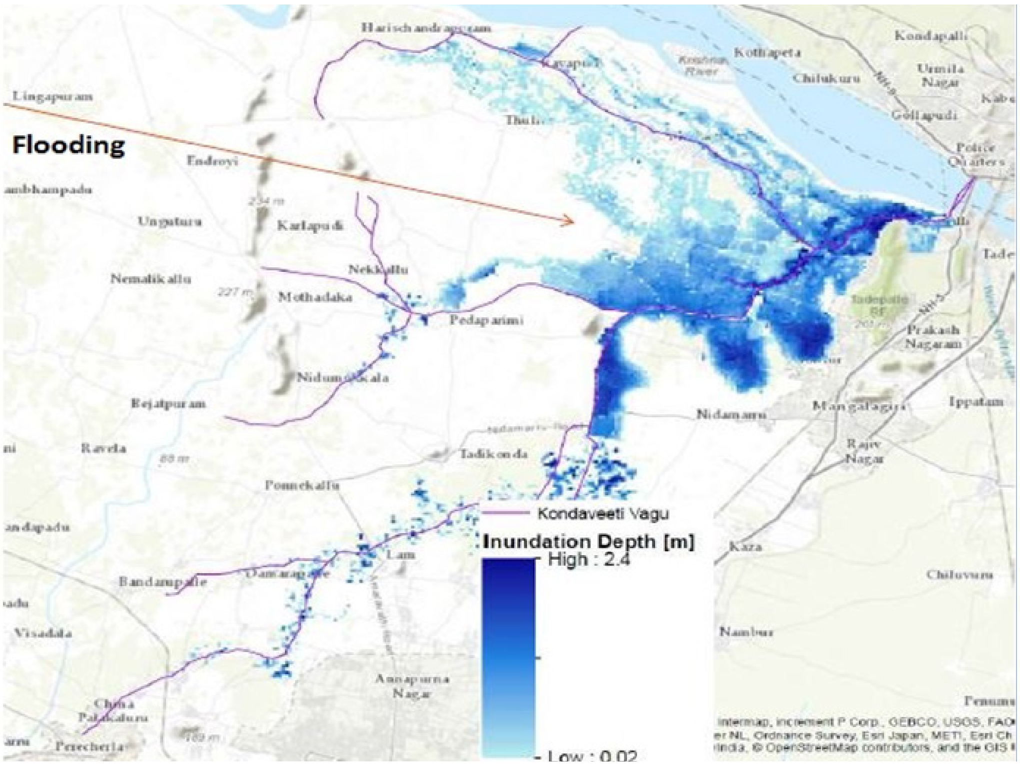



**FIGURE 11:**
Inundation levels for 100-year flood

*Source: Tata-Arcadis analysis for Amaravati*

4 Based on satellite imagery and topographical surveys, the ground levels at the Seed Development Area (area between Palavagu and the Krishna River) are higher than the reported inundation level. The satellite data/imagery is not sufficiently accurate, and therefore currently it is not possible to determine the actual area of inundation based on the existing data. The actual platform levels are subject to a more detailed hydrological and hydraulic analysis of the Kondaveeti Vagu.

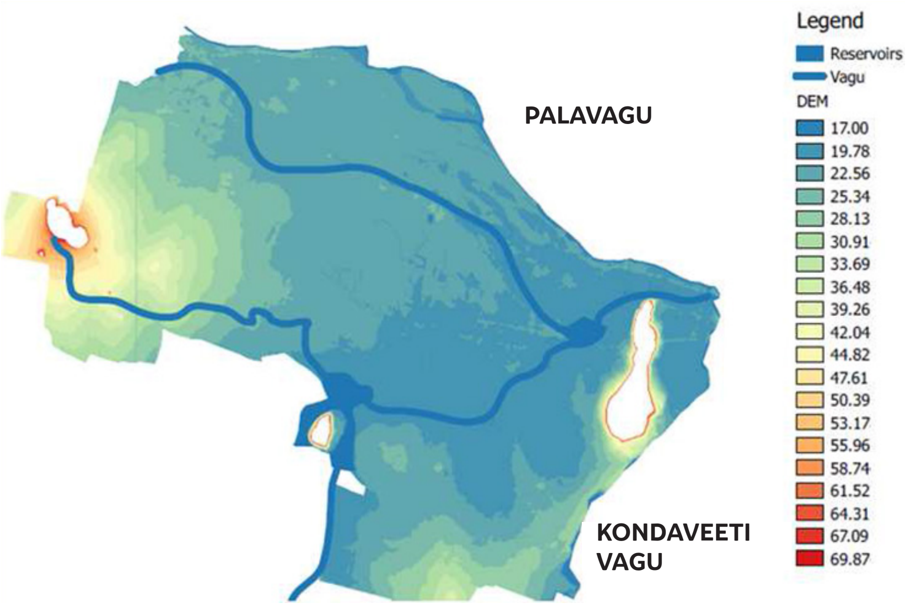



**FIGURE 12:**
DEM-based on satellite imagery and surveys

*Source: APCRDA report*

5 The ground levels in the Seed Development Area are relatively high, and slope gently from west to east. Based on the digital elevation maps provided by APCRDA, the ground level in the west is +26m average mean sea level (AMSL), whereas the lowest ground is in the southeast area with an estimated level of +23m AMSL. The blue consultants modelling study also indicated similar levels in Kondaveeti Vagu.

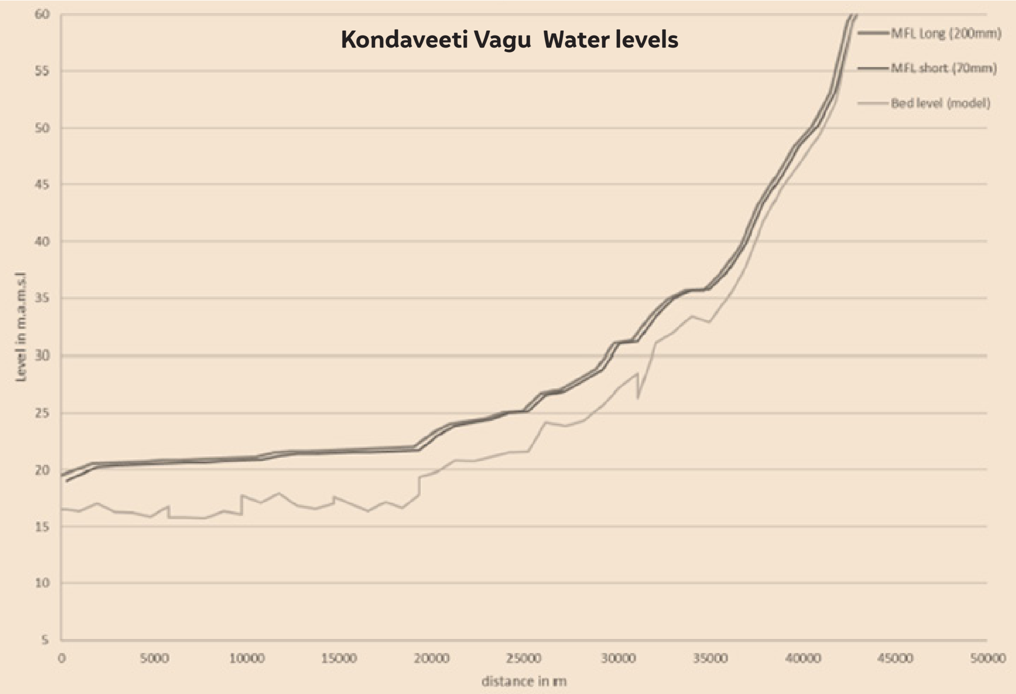



**FIGURE 13:** Estimates of flooding levels for Kondaveeti Vagu river

*Source: Draft Tata-Arcadis report for Amaravati*

6 Since the inundation levels from the Kondaveeti Vagu as discussed above are below the flood levels of the Krishna River, it is proposed to pump the flood discharges of the Kondaveeti Vagu into the Krishna. As per the consultants, the estimated volume of flood discharge requiring pumping is around 18,000 cusecs (510 cumecs). The consultants also presented an alternative flood mitigation proposal to intercept the catchment outside the city area and to divert about 160 cumecs through an artificial canal into the Krishna River at an upstream location (Venkatapuram).

7 The report suggested expanding the carrying capacity of the Kondaveeti Vagu by increasing its width in order to contain the flood discharge within the drain, thereby preventing inundation. To protect the capital city area from flooding, it is proposed to construct diversion drains that will channel storm water along the boundaries of the site into the Krishna River. The Seed Development Area would provide drainage for internal rainfall in the area without allowing external flows through the site. A city-level detailed drainage plan is not available for review.

8 The report on the city development plan had also described the follow-up actions on the basis of the above-mentioned findings, including several hydraulic, dredging, and river morphological studies, before undertaking any bund alignments, creating water channels (drainage), or raising ground levels, including developments on adjacent island. These actions are listed in Table14.

| Realignment and Strengthening of Krishna River Bund | |
|---|---|
| 1. | Undertake a detailed study of the partial realignment of the existing bund, so that more riverfront land can be retained for Seed Development |
| 2. | Design and construct the new stretch of realigned bund and lower existing bund to platform level |
| **Raising of Platform levels for the Seed Development and Island** | |
| 3 | Carry out dredging and hydraulic study to ascertain the availability and suitability of fill materials from Krishna river, and the environmental and hydraulic impact |
| 4 | Conduct a hydrological and hydraulic study of Krishna river and Kondaveeti Vagu and carry out dredging work to create water channels |
| 5 | Carry out detailed topographical survey of Seed Development to determine exact extent of area to be raised. |
| 6 | Raise the platform levels within Seed Development to +25m average mean sea level (indicative) matching existing villages |
| 7 | Raise platform level of island to existing bund level (subject to dredging & hydraulic study of Krishna river) |
| **Construction of diversion drains serving the Seed Development, including outfall structures** | |
| 8 | Design and construct main drains and outfall structures according to Singapore or Indian code of practice (whichever is more stringent) |
| 9 | ABC water features to be considered where possible |

**TABLE 14:** Follow-up actions as detailed in the Seed Development Plan

*Source: Draft Seed Development Plan*

## 3.4.2 Climate change impacts on flood management for Amaravati

The following projected climate changes and their potential impacts and risks for flood management are given in Table 15.

| Projected climate changes | Potential impacts and risks |
|---|---|
| More intense and more frequent high-temperature extremes and longer duration of dry spells. Temperatures are expected to rise by 3.7°C on average from 1981-2010 to 2071-2100. If emissions were to decrease rapidly, this rise could be limited to about 1°C on average. | Increase in temperature due to climate change will alter evapotranspiration rates and soil moisture conditions, resulting in variability in catchment runoff and flood discharge. |

**TABLE 15:** Impacts of climate change on flood management

*Source: Authors' analysis*

**TABLE 15 contd**

| Projected climate changes | Potential impacts and risks |
| --- | --- |
| Higher annual rainfall totals and more frequent/heavy-rainfall events. Longer duration of dry periods. As explained in the chapter on climate change in this report, under a high-emissions scenario, total annual rainfall is expected to increase by about 13% (about 125mm) on average from 1981-2010 to 2071-2100. If emissions were to decrease rapidly, this rise could be limited to about 30mm on average. | Potential increase in flood risks/flash floods and overburdening of city drainage infrastructure. If there is no planning to accommodate these extreme floods due to climate-change effects, low-lying areas would be inundated during flash floods associated with high-intensity rainfall. |

The GCMs predict notable climate variations for Amaravati. As explained in the chapter on climate change in this report, under a high-emissions scenario, total annual rainfall is expected to increase by about 13 per cent (about 125mm) on average from 1981-2010 to 2071-2100.

Increase in rainfall by about 13 per cent as a result of climate change would result in increased flooding in Amaravati. Also, changes in the pattern of precipitation may alter the flood hydrographs and flooding patterns. Excessive rainfall or more intense rainfall could result in flash floods, and hence city-wide preparedness is important for dealing with such sudden flash floods. Increase in temperature due to climate change could alter the evapotranspiration and soil moisture conditions, resulting in variability in runoff discharges, which needs to be addressed through suitable drainage infrastructure for Amaravati.

Considering the above-mentioned projected changes in temperature and precipitation levels, flood modelling studies need to be undertaken and flood mitigation systems need to be developed. Some suggestions are:

- Increased flood discharge due to climate change should be taken into consideration while designing the carrying capacity of Kondaveeti Vagu and its drainage system.
- The high flood level and moderate flood level markings and discharge data used for the design of bridges and underpasses should be revised on the basis of the findings of climate change studies. Appropriate allowance for additional discharge/levels due to climate change should be made in the design of culverts, embankment levels, bridge soffit/invert levels, and waterways. Strengthening of the Krishna River's bund along Amaravati needs to be reviewed considering the additional discharge that the river may receive due to climate change. If required, the bund could be extended further upstream to avoid flooding of areas upstream of the city's periphery. Often it is not the over-topping but rather the strength the bund that plays a major role of in preventing the flooding of the adjacent areas.
- The pumping of flood discharge from the Kondaveeti Vagu into the Krishna River should be reviewed, considering additional discharge due to climate-change effects. The energy required for this pumping and for the maintenance of pumping systems under the climate-change scenario could be more expensive.

- If the capital area were to have raised ground (platform) levels, these would restrict runoff / flood discharges from the upstream catchment area. Hence, this issue needs to be addressed. This will be critically important under climate-change scenarios because the frequency of flooding and the quantum of run off are also projected to increase on account of climate change.
- Flood mitigation/management should receive due attention considering that very major changes in land-use and flood-flow patterns are projected to occur compared to present conditions. These changes under climate-change conditions are worth including in assessments of flood management.
- The city drainage system needs to be designed considering additional discharges from the upstream drains and additional discharges from the rooftops of civic and residential buildings under climate change.
- Water usage increases when temperatures rise, and hence the volume of waste water flowing into drains also increases during summer and dry seasons. This aspect needs to be considered when designing drains for the dry period.
- Since Amaravati is located on a major river, a basin-level study is needed to estimate flood risks considering catchments on the upstream.

Based on the above discussion points, a flood management roadmap (i.e. actions to be taken in the short, medium, and long terms) is proposed in Table 16.

**TABLE 16:** Key recommendations for climate-resilient flood management

*Source: Authors' analysis*

| Short-term recommendations | Mid-term recommendations | Long-term recommendations |
|---|---|---|
| • Since the city development plan is being implemented on open land, the flood management plan needs to be reviewed considering intense rainfall as envisaged based on the results of climate modelling.<br><br>• Assessment of flood risk due to high-intensity rainfall and resulting flash floods should be included in disaster management plans for the city.<br><br>• Use of hydraulic models to project runoff under intense-rainfall events and estimate of inundation under climate-change scenarios would help in reviewing emergency plans for flood management.<br><br>• Integration of land-use planning and water management should be key aspects of planning. | • Review flood return periods under changing climate scenarios and consider appropriate rainfall intensities in estimating runoff and flood discharges.<br><br>• Flood control structures should incorporate climate-change factors into their designs.<br><br>• Designs of reservoirs, appurtenances, and structures should consider adequate flood discharges to ensure resilience against climate-change effects.<br><br>• Effective management of flood-control reservoirs and canal systems should be ensured through the use of SCADA.<br><br>• Establish an early warning system. Warning at an early stage enables | • Make alternative arrangements to divert flood waters and install pumping systems.<br><br>• Ensure early prediction of floods through the use of robust hydrological and hydraulic models, which could take predicted hydro-meteorological data and estimate the flood situation and issue an early warning.<br><br>• Since the city abuts a major river, a basin-level study is required to estimate floods risks considering the catchment area upstream.<br><br>• Maintenance of greenery on side slopes along canals and water bodies is necessary to increase the capacity to resist erosion caused by flash floods under climate-change scenarios. |

**TABLE 16 contd**

| Short-term recommendations | Mid-term recommendations | Long-term recommendations |
|---|---|---|
| • Flood management policy and institutional framework structure, including O&M strategies, should be reviewed to address climate resilience in flood management.<br><br>• The design of new flood control reservoir systems and dams should consider the impacts of climate change while building as well as during operations and maintenance.<br><br>• Interdependent policies for water storage and flood control need to be reviewed from the point of view of climate-change effects.<br><br>• Planned flood management infrastructure should be resilient to risks posed by potential increases in rainfall and flood discharges, and should be accounted for in investment decisions.<br><br>• Conduct climate-change impact and adaptation training for personnel working in interdisciplinary areas of flood management.<br><br>• Launch public awareness programmes on climate-change effects and on flood management and climate resilience plans that should be followed during high floods and intense rains. Set up information broadcasting systems for public communication. | people to take necessary precautions and to make preparations to limit the effects of a flooding as far as possible.<br><br>• Establish an institution to disseminate and monitor information about water levels /inundation extents and to issue warnings to the responsible authorities in case of alarming high water levels, in cooperation with the command and control centre through which the entire system of flood control/mitigation will be monitored, controlled, and operated.<br><br>• Adequately maintained and trained staff and work teams should be made available for undertaking effective flood management. For this they would coordinate with national-level teams like the National Disaster Management team that have the ability to monitor the flood management system using technological tools like GIS and weather radars.<br><br>• Encourage local communities to participate in flood management activities. Train them to disseminate information on severe floods and good practices to adopt for developing resilience during floods. | • Increase water storage capacity, including silt removal, of existing reservoirs; construct new reservoirs and/or dams to accommodate flood discharge during higher-return periods.<br><br>• Greater cooperation with neighbouring riparian states should be pursued to share and disseminate information on floods to affected communities and to use the shared data for making early predictions of flood risks for states located downstream.<br><br>• Regardless of the strategy that is eventually decided, a residual risk will always remain. This residual risk should be taken as a tolerable risk and safety standards should be evolved.<br><br>• Promotion of green infrastructure as already planned would reduce greenhouse gases and help in moderating the local climate overall. |

Investments in storm water infrastructure should factor future scenarios of increased rainfall.

Image: iStock

# 4. Amaravati climate resilience framework and roadmap

Global temperatures are climbing. The increase so far is already unleashing acute events. Building resilience is essential. In the next 10 to 20 years, the extreme-weather events that we currently experience only occasionally will become more normal. Beyond 20 years, we will see the emergence of chronic (long-term) climate impacts. Urban planners and infrastructure owners, operators, and investors need to integrate climate change into their strategic plans to protect against acute events that are already occurring and to prepare for the added impact of chronic events in the future.

From the Climate Change Risk Profile for Amaravati (Appendix A), the following expected changes in future temperature and rainfall, and the projected subsequent impacts on transport and water infrastructure, energy demand, and flood management are summarised in Table 17.

| Temperature-related changes expected: Warmer conditions, including more intense and frequent high-temperature extremes: | Temperature-related impacts expected: Leading to more prolonged hot periods and heatwaves, causing problems for infrastructure integrity: |
|---|---|
| Increasing mean temperatures<br>Increasing number of warmer days<br>Increasing number of warmer nights | **Transport infrastructure** - heat damage to component materials, cracking, expansion of bridge joints<br>**Water supply infrastructure** - low flows, increases in evaporation, reduced water quality, increased risks of water shortages<br>**Energy demand** - increase in power demand and requirement for cooling and water pumping, reduced demand for heating<br>**Flood management** - altered evapotranspiration and soil moisture, increasing variability in runoff and discharge |

**TABLE 17:** Potential future climate change and impacts on key infrastructure sectors

*Source: Authors' compilation*

**TABLE 17 contd.**

|  | **Rainfall-related changes expected:**<br>Warmer conditions, including more intense and frequent high-temperature extremes: | **Rainfall-related impacts expected:**<br>Leading to more prolonged hot periods and heatwaves, causing problems for infrastructure integrity: |
|---|---|---|
| | Higher total rainfall<br>More frequent heavy-rainfall days<br>More consecutive dry days | **Transport infrastructure** - overloading of drainage system, flood and storm/wave damage to transport routes<br>**Water supply infrastructure** - flooding/flash flood risk damage as infrastructure and storage system are unable to accommodate excess water, thereby overwhelming sewer capacity<br>**Energy demand** - changing precipitation patterns could affect hydropower prospects positively or negatively<br>**Flood management** - increased risk of flooding/flash floods,leading to damage and inundation |

The combination or cumulative episodes of two or more of the above can lead to greater direct and indirect impacts. Other potential hazards include:

- Urban heat island effects
- Precipitation-induced landslides
- Air pollution episodes
- Wildfires

To understand the likely impacts on the sectors reviewed in this study, Table 18 summarises those impacts identified in the sectoral reviews.

**TABLE 18:** Examples of climate impacts on sectors

*Source: Authors' compilation*

| | **Transport infrastructure** | **Water supply infrastructure** | **Energy demand** | **Flood management** |
|---|---|---|---|---|
| <br>**Temperature** | Rise in asphalt temperature may compromise pavement integrity, affecting entire road network<br>Thermal expansion of bridges across Krishna river | Reduced water yields due to decline in quantity of water (due to low flows, increases in evaporation, and reduced water quality)<br>Unsustainable demand on water services, resulting in increased risks of water shortages<br>Increased energy consumption for operations and maintenance of water infrastructure | Increase in power demand and in energy requirement for cooling, water pumping<br>Reduced energy requirements for heating | Increasing temperatures alter evapotranspiration rates and soil moisture conditions, resulting in variability in the catchment runoff and flood discharges<br>Putting pumping stations are placed under additional strain |

**TABLE 18 contd.**

| | Transport infrastructure | Water supply infrastructure | Energy demand | Flood management |
|---|---|---|---|---|
| Rainfall | Flood damage to roads, railway, MRT lines close Krishna River<br>Drainage systems likely to be overloaded more frequently and more severely<br>Storm surge/wave action will cause more frequent interruptions to inland waterway | Potential increase in flood risks/flash floods because storage reservoirs and city drainage infrastructure are not planned to accommodate these extreme events<br>Sewer flooding caused by rainfall, overwhelming sewer capacities<br>Possible implications for maintaining water balance and for maintaining quantity and quality of water resources | Changing precipitation patterns could affect hydropower prospects positively or negatively | Potential increase in flood risks/ flash floods for city drainage infrastructure<br>Inundation of low- lying areas will occur during flash floods associated with high-intensity rainfall |

When considering climate resilience and how it could be designed for, and invested in, the development of Amaravati city, some resilience measures were investigated for a number of sectors. These are described in Table 19.

**TABLE 19:** Examples of potential resilience measures

*Source: Authors' compilation*

| | Transport infrastructure | Water and waste water infrastructure | Energy demand | Flood management |
|---|---|---|---|---|
| Temperature | Using heat-resilient paving materials,building heat-tolerant streets, and adopting landscape protection<br>Designing infrastructure for higher maximum temperatures<br>Shifting construction schedules to cooler parts of day | Build systems to recycle waste water for energy, industrial, household, and agriculture use<br>Practise water conservation and demand management | Additional sourcing of power, increasing renewable energy production and storage to help meet increasing demands and demand peaks | |

**TABLE 19 contd.**

| | Transport infrastructure | Water and waste water infrastructure | Energy demand | Flood management |
|---|---|---|---|---|
| **Precipitation** | Upgrading road drainage systems<br>Increasing the drainage capacity standard<br>Grooving and sloping pavements | Promote green infrastructure (e.g. green roofs, filter strips, and permeable materials) to reduce runoff and pollutants into the storm water collection system and into surface water bodies | Additional sourcing of hydropower, increasing renewable energy production and storage to help meet increasing demands and demand peaks<br>Increase water storage capacity (including through silt removal) at existing reservoirs; construct new reservoirs and/or dams | Flood management policy and institutional framework structure, including O&M strategies, need to be reviewed to address climate resilience in flood management<br>Increase water storage capacity, including through silt removal, at existing reservoirs; construct new reservoirs and/or dams to accommodate flood discharge from floods of higher return periods<br>Make alternative arrangements to divert flood waters and set up pumping systems |
| **Applicable to all sectors** | Increasing the number of warnings from an Early Warning System and providing updates to dispatch centres, crews, and stations on extreme events<br>Creating awareness about climate risks and generating demand: Bottom-up approach | | | |

## 4.1 Overview of framework

Based on international good practice pertaining to climate assessment and resilience planning, the following high-level framework (Figure 14) has been developed in the context of the Indian cities included in the project with a focus on city infrastructure resilience.

This framework is needed to enable the integration of climate resilience into city planning, design, and operation, as well as into policies and programmes. The framework has been tailored to the specific needs, objectives, and local contexts of Indian cities. The resilience framework helps Indian cities understand the impacts that a changing climate could have on their city and shows them how to plan and monitor the actions they need to take.

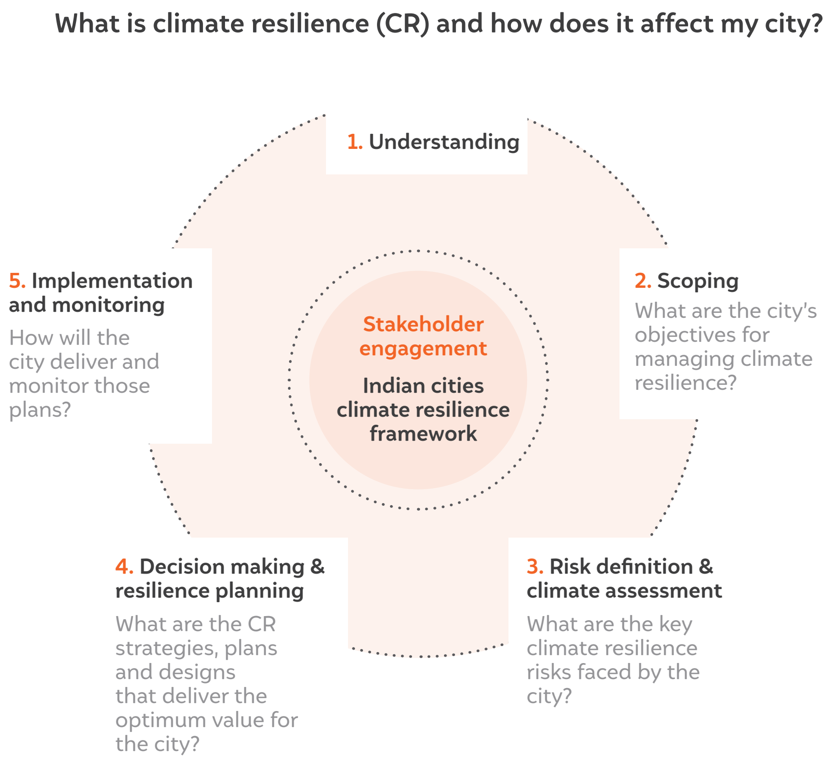



**FIGURE 14:** Overview of climate-resilience framework for Indian cities

*Source: Authors' compilation*

Further details under each of the steps set out in the resilience framework are given below. This framework has been developed to capture high-level steps and tasks that should be taken to aid Indian cities in planning and taking actions to increase climate resilience. Based on the work carried out in this project, progress against the earlier steps has been started and is highlighted, where relevant, for the city of Amaravati. Further work as a follow-on to this project would be needed to look to move the framework forward and to provide more tailored guidance and practical advice on how to undertake the key tasks.

### 4.1.1 Step 1. Understanding

In getting started, Step 1, which is on understanding, seeks to find out what climate resilience is, how it is relevant, and how it affects the city.

| 1. Understanding<br>What is climate resilience? How does it affect my city? | | | Progress check |
|---|---|---|---|
| Step | Purpose | Key tasks | Monitoring progress for Amaravati |
| 1.1 | Understand what climate change and climate resilience are and why they are important for the city | Conduct awareness-raising programmes with city officials and staff of technical sector/ department<br><br>Hold interactive training sessions with senior officials and staff of sector/department | Initial discussions on climate resilience held with city development officials in October 2016<br><br>*Status: Started, further work needed* |
| 1.2 | Define context and baseline, and collate relevant data | Collect available data on the wider context relevant to the city and the wider region; review quality of data; and identify any gaps in data.<br><br>Identify all potential climate-and non-climate-related risks and parameters. | Data and information collected on wider context from national-level policies, master plans, EIAs, presentations, climate projections<br><br>*Status: Started, further work needed* |
| 1.3 | Agree on the support and resources required | Get senior-level support for conducting climate-resilience assessment.<br><br>Form a team (with a minimum of two people) for undertaking the general climate-resilience assessment. | Senior-level commitment to participating in FCO project has been given; further commitment is needed to continue the FCO project and to form a working group or team to conduct a more detailed assessment across more sectors.<br><br>*Status: Further commitment needed* |
| 1.4 | Ensure stakeholder engagement, communication, and transparency | Identify and engage with all relevant stakeholders | *Status: Not started* |

*Source:*
*Authors' compilation*

## 4.1.2 Step 2. Scoping

Once the context and understanding of climate resilience has been established, step 2, i.e. scoping, seeks to identify and set out the city's objectives for managing climate resilience.

| 2. Scoping<br>What are the city's objectives for managing climate resilience? | | | Progress check |
|---|---|---|---|
| Step | Purpose | Key tasks | Monitoring progress for Amaravati |
| 2.1 | Define study environment and scope | Define study boundaries, sectors, focus, priorities, and purpose<br><br>Set out plan for systems approach to the assessment<br><br>Identify which stakeholders need to be involved (relevant city departments, utilities, service providers, asset owners, other groups and communities, etc.) | FCO study focused on Amaravati city boundary and four sectors only<br><br>*Status: Started, further work needed* |
| 2.2 | Define wider context | Understand the wider context of links to national and regional objectives, strategies, and commitments (e.g. SMART city plans, State Action Plan on Climate Change, plans for new capital)<br><br>Identify major opportunities for early intervention - planned and likely future city developments | Data and information on regional context collected<br><br>*Status: Started, further work needed* |
| 2.3 | Establish baseline for assessment | Identify current and existing non-climatic and climatic threats and opportunities<br><br>Collate details of past extreme events, and any thresholds reached | More detailed assessment needed<br><br>Past events harder to collate given new city status<br><br>*Status: Started, further work needed* |

*Source:*
*Authors' compilation*

## 4.1.3 Step 3. Risk definition and climate assessment

In moving from scoping to risk definition and climate assessment, Step 3 asks what are the key climate-resilience risks faced by the city.

| 3. Risk definition and climate assessment<br>What are the key climate-resilience risks faced by the city? | | | Progress check |
|---|---|---|---|
| Step | Purpose | Key tasks | Monitoring progress for Amaravati |
| 3.1 | Assessment of likely future climate of city | Trend of various climate variables (e.g. average temperature, heat days, intense rainfall events), based on one or ideally on a range of different climate scenarios, their implications and limitations<br><br>Identification of percentage change ranges for relevant climate variables | Latest climate projections and assessment based on Global Climate Models completed<br><br>*Status: Completed based on information from available sources; more regional and local modelling could be considered* |
| 3.2 | Assessment of climate risks facing the city systems | Expected (direct and indirect) impacts (threats, opportunities) indicated by identifying the most relevant hazards and the areas of the city most at risk given an overlay of spatial distribution of the total population, vulnerable populations, economic activities, and economic value<br><br>Indication of impacts of timescales (short/ medium/longer term)<br><br>Indication of level of confidence (high/ medium/low) regarding handling such impacts | Initial analysis completed for four sectors under FCO project. More detailed assessment needed.<br><br>*Status: Started* |
| 3.3 | Define acceptable level of risk | Define the level of risk that the city is prepared to bear or the level of resilience it is willing to build<br><br>Set out the minimum amount of disruption the city is aiming to face during an extreme event | *Status: Not started* |

*Source:*
*Authors' compilation*

### 4.1.4 Step 4: Decision-making and resilience planning

Step 4 moves from defining the key climate-resilience risks to describing how they affect decision-making and the development of a resilience plan.

| 4. Decision-making and resilience planning<br>What are the climate-resilience strategies and plans that deliver the optimum value for the city? | | | Progress check |
|---|---|---|---|
| Step | Purpose | Key tasks | Monitoring progress for Amaravati |
| 4.1 | Identify relevant climate-resilience measures | Using local knowledge, expert advice, and information from similar cities, identify potential resilience measures against all major risks relevant to the city<br><br>Assess potential costs and benefits and other supportive processes that may be needed to ensure implementation | FCO project suggested initial resilience measure for consideration for selected sectors<br><br>*Status: Started, further work needed* |
| 4.2 | Implement climate-resilience measures and climate-induced disaster risk planning | Select and prioritise resilience measures in consultation with relevant stakeholders<br><br>Develop a draft resilience plan to collate all activities and to provide strategic direction | FCO project suggested roadmap be given to get started on the development of a plan<br><br>*Status: Started, further work needed* |
| 4.3 | Integrate climate-change adaptation and resilience into decision-making process | Identify centralised ways of supporting implementation of the measure by changing existing or upcoming city policies, planning requirements, and supplier and contract requirements | FCO project sets out ways of supporting implementation suggested in overarching roadmap<br><br>*Status: Started, further work needed* |

*Source:*
*Authors' compilation*

### 4.1.5 Step 5: Implementation and monitoring

In Step 5, the climate-resilience plan is implemented and monitored by the relevant parties.

| 5. Implementation and monitoring<br>How will the city design deliver and monitor those plans? | | | Progress check |
|---|---|---|---|
| Step | Purpose | Key tasks | Monitoring progress for Amaravati |
| 5.1 | Formalisation of climate-resilience plan | Assign ownership and responsibility along with timeframes for reporting progress against resilience measures<br><br>Get approval and commitment from senior city officials<br><br>Set out timeframes for reporting and for conducting periodic reviews | *Status: Not started* |
| 5.2 | Implementation of climate-resilience plan | Carry out plan actions and regularly report on progress made<br><br>Provide support to ensure implementation (resources, capacity building, guidance for different actors) | *Status: Not started* |
| 5.3 | Monitoring, reporting, and evaluation of climate-resilience plan | Undertake periodic reviews; report risks and progress made in implementing resilience plan (linked to existing reporting cycles).<br><br>Gather and communicate lessons learned; list recommendations for next iteration of resilience plan.<br><br>Undertake formal review and evaluation with relevant stakeholders.<br><br>Agree on new or revised actions and update resilience plan | *Status: Not started* |

*Source:*
*Authors' compilation*

## 4.2 Overarching climate resilience roadmap for Amaravati

An overarching climate resilience roadmap covering priority actions in the short, medium, and longer terms is given in Figure 15. It sets out the immediate and next steps for integrating the climate resilience framework into the planning and policy-making for Amaravati city.

Sector-specific roadmaps, with details of resilience recommendations over the short to longer terms, are given in the sectoral analysis section of the previous chapter of the report.

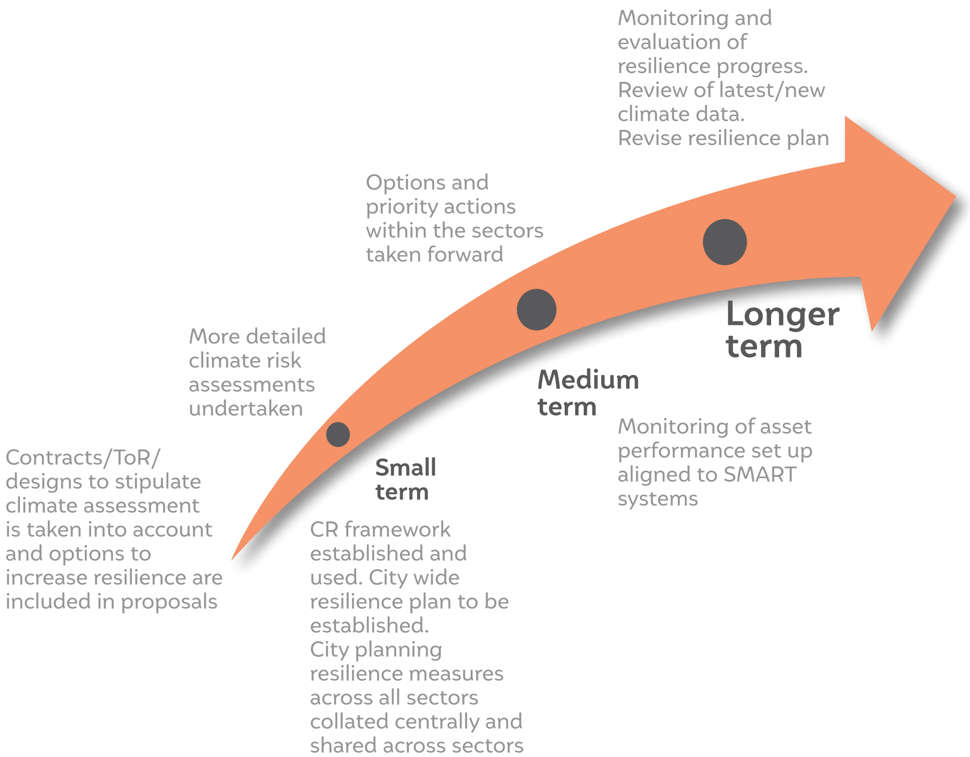



**FIGURE 15:** Overarching climate resilience roadmap

*Source: Authors' compilation*

## 4.3 Draft of text on climate resilience for inclusion in Terms of Reference, contracts, and commissioning work

To make immediate progress, and to take advantage of the opportunity to plan for Amaravati's development before large infrastructure contracts and construction works are awarded, it is recommended that a section on the need to undertake a climate-screening assessment, and consideration of designs and options to increase resilience of any proposed plans, designs, and developments by the city and its contractors, should also be incorporated. Below is an example of such a draft text that could be tailored and used by APCRDA immediately for inclusion as standard text in the relevant Terms of Reference to ensure that climate resilience is considered as early as possible in the development of the city.

Draft of text on climate resilience for inclusion in Terms of Reference, contracts, and commissioning work:

### High-level screening to identify priority risk areas that require more detailed assessment

The high-level screening is undertaken by means of literature review and qualitative assessment in order to identify the priority risk areas that will require more detailed assessment. At the optioneering or solutioning stage, the robustness of options against a range of futures, including climate scenarios, should be considered.

- The high-level screening should cover the expected lifetime of the asset (likely up to the 2050s), with a special focus on the concession period for the funding and operation of the asset. Its scope should include the identification of:
- Current climate risks in the city and in the immediate surrounding area, with examples from recent experience, where available;
- Context of regional climate change and risk;
- Potential direct impacts on the infrastructural systems, assets, and planned developments;
- Potential indirect impacts such as climate-driven changes in land use and water demand;
- Potential interdependencies between critical infrastructural links, nodes, and hubs and their supporting infrastructure.

At a minimum, the high-level screening should include a qualitative appreciation of the impacts of climate change on:

- Extreme flood events (which might affect Probable Maximum Flood)
- Extreme high temperature and dry events (which could lead to heatwave and drought conditions, thereby affecting the integrity of the infrastructure and its operation)

On completion of the high-level screening, relevant climate modelling data for the region should also be collected in preparation for the detailed risk assessment. The assessment should cover the full range of future climate change that can be expected (not just the results from a limited subset of General Circulation Models [GCMs] or Regional Climate Model experiments), as based on the most recent results from experiments.

The **Amaravati Climate Risk Profile** provides an initial compilation of climate projections and observed changes that are relevant for Amaravati, with projected temperature and rainfall changes drawn from the current Intergovernmental Panel on Climate Change Fifth Assessment Report GCMs, alongside key messages and implications for the climate change risk assessment of the Amaravati development. This Climate Risk Profile is included as an annexure to this Terms of Reference. It should be used as the starting reference point for the assessment of the climate model data as part of the high-level screening and as the next step of a more detailed Climate Change Risk Assessment if a number of important risks are identified in the high-level screening.

**Detailed climate change risk assessment undertaken as part of the broader Risk Management Plan**

A detailed climate change risk assessment should focus on the significant risks identified during the high-level screening stage, and should be undertaken with the agreement of Amaravati city authorities. It should be based on a combination of literature review, data analysis, and risk modelling for a range of scenarios. The analysis should consider the full range of likely potential climate change.

**Risk management and climate-resilience plan**

The purpose of this stage is to set out the recommended approach to address priority risks. The effort at this stage should focus on those risks identified as significant. It may be appropriate to involve experienced specialists in assessing the associated risk topics to satisfy themselves about any change to the risk profile and to confirm the best way of managing the identified risks.

A risk management plan should be produced to ensure that any design options that are currently not resilient under climate-change scenarios can be addressed appropriately.

*Source:*
*Authors' compilation*

# Appendix A. Amaravati climate risk profile

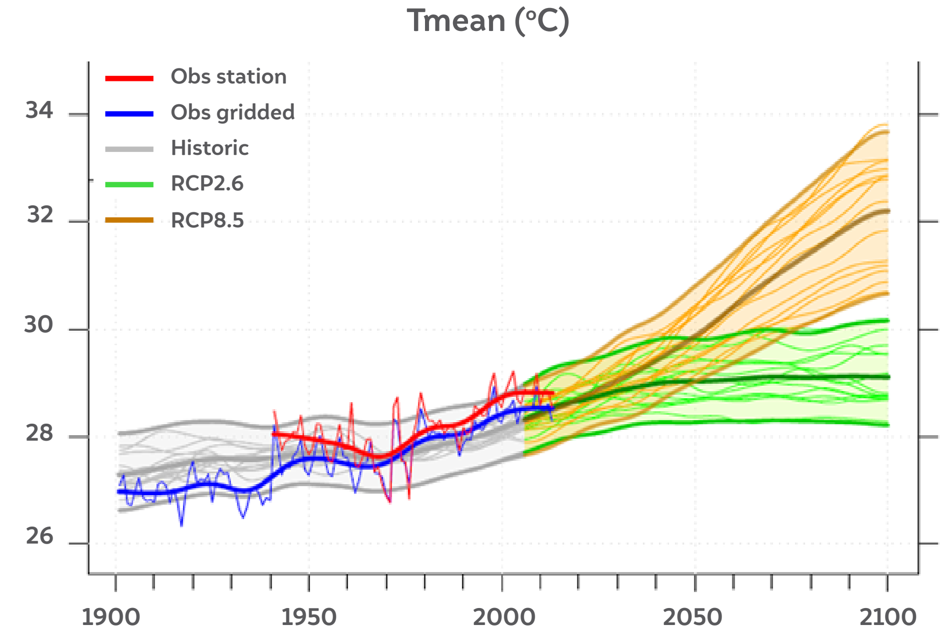



**FIGURE A1:** Increases in mean temperature for Amaravati

*Source: Authors' analysis*

Both observations and simulations show an upward trend in mean annual temperature, which has accelerated from around 1970 onwards. Under a high-emissions scenario, this trend is projected to continue until the end of the century, with a rise of 3.7°C on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise will be limited to about 1°C on average.

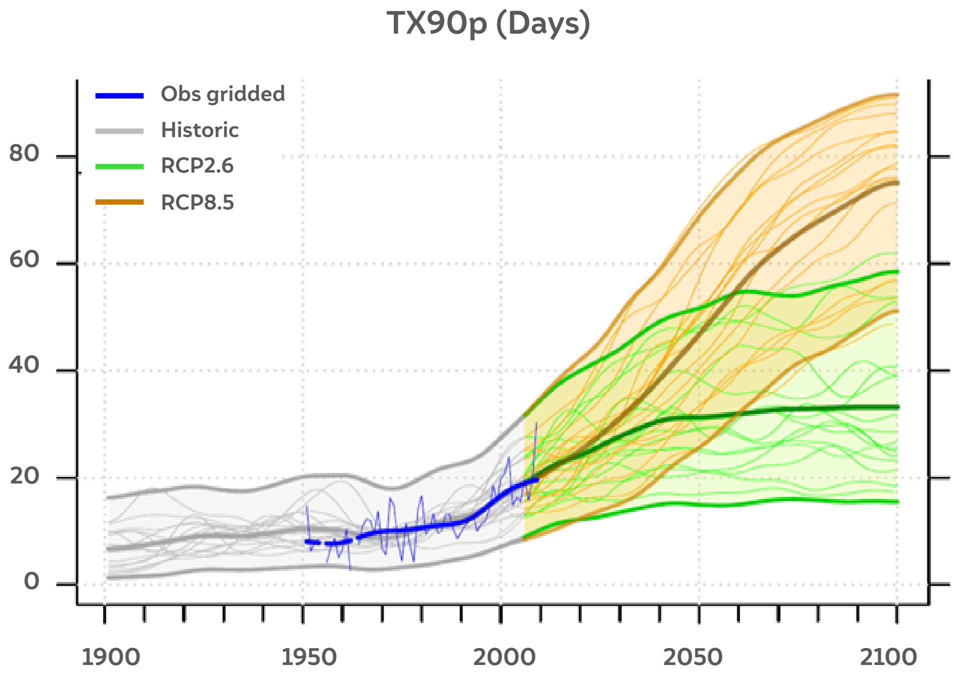



**FIGURE A2:** Increases in temperature extremes for Amaravati

*Source: Authors' analysis*

The observations and simulations are consistent in indicating more high-temperature extremes (warm days and warm nights, days of heat wave) and fewer cold-temperature extremes (cold days and cold nights, days of cold wave). The number of warm days (shown here), for example, is projected to increase by about 55 days on average from 1981-2010 to 2071-2100 under a high-emissions scenario (and the number of heat-wave days is projected to increase by around 200 days on average). If emissions decrease rapidly, the rise in warm days will be limited to about 20 days on average (and the rise in heat-wave days will be about 55 days on average).

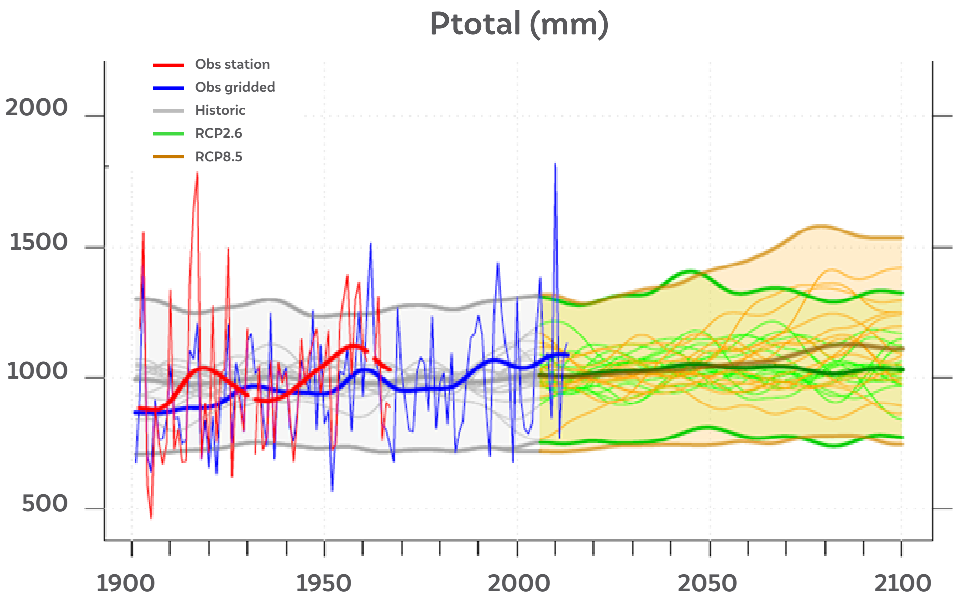



**FIGURE A3:** Increases in mean precipitation for Amaravati

*Source: Authors' analysis*

Both observations and simulations show a tendency towards increasing total annual rainfall, although year-to-year variability is large. Under a high-emissions scenario, total annual rainfall is projected to increase by about 13 per cent (about 125 mm) on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise will be limited to about 30 mm on average.

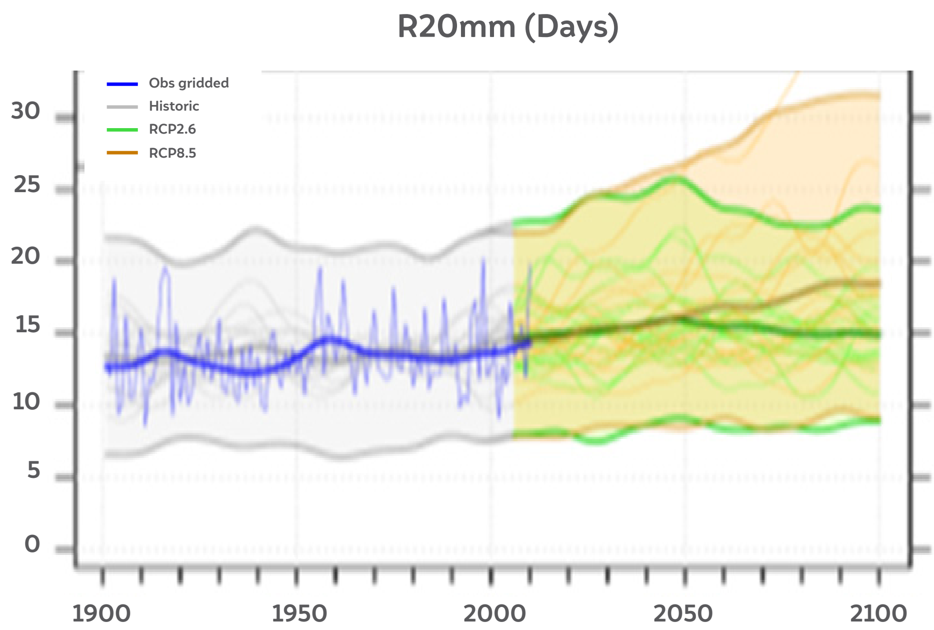



**FIGURE A4:** Number of heavy-rainfall days for Amaravati

*Source: Authors' analysis*

The observed record of heavy-rainfall events tends to be dominated by decade-to-decade and year-to-year variability. For the projections, there is a tendency towards more frequent heavy-rainfall events. The number of days per year with rainfall greater than 20 mm (shown here), for example, is projected to increase by about 4 days on average from 1981-2010 to 2071-2100 under a high-emissions scenario. Some models indicate increases well outside the range of observed variability, indicating an even greater increase in risk. On the other hand, the number of consecutive dry days (not shown) shows little change (and perhaps even a slight increase with high emissions) from an average of about 100 days, with continuing large year-to-year variability.

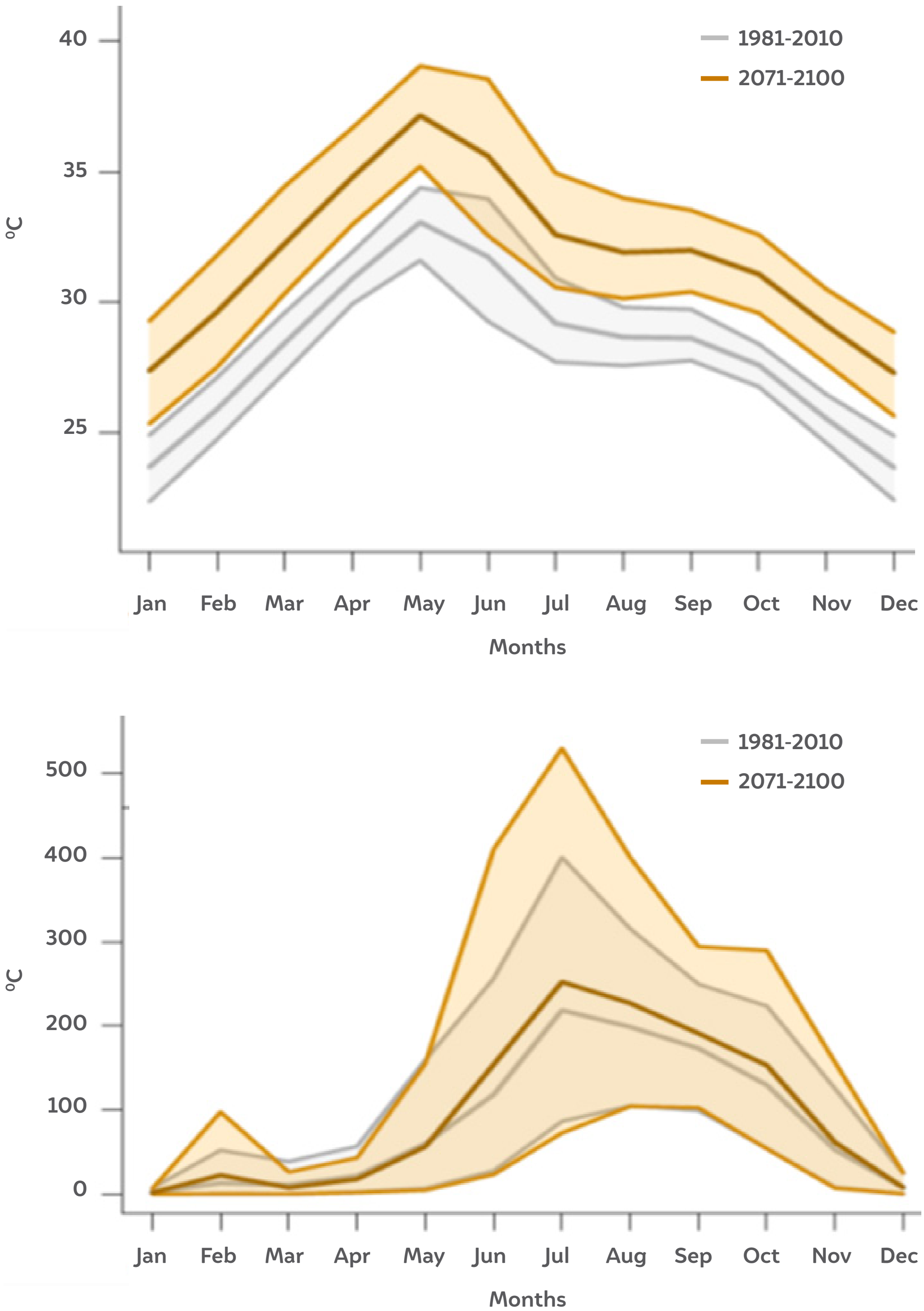



**FIGURE A5:** Simulated seasonal cycles of monthly temperature (top) and rainfall (bottom)

*Source: Authors' analysis*

These figures show the simulated seasonal cycles of mean monthly temperature (top) and total monthly rainfall (bottom) for 1981-2010 (grey) and 2071-2100 for the high RCP 8.5 emissions scenario (orange). The thick lines show the multi-model average, while the shading provides a measure of uncertainty. No changes are evident in the timing of peak temperature (May) or peak rainfall (July).

**TABLE A:** Observed and projected changes in temperature and rainfall for Amaravati

*Source: Authors' analysis*

| | Observed 1981-2010 | 2030s - RCP8.5 | 2050s - RCP8.5 | 2080s - RCP8.5 | 2080s - RCP2.6 |
|---|---|---|---|---|---|
| **Temperature** | | | | | |
| Mean temperature | 28.3°C | +1.2 (0.8 to 1.5) °C | +1.8 (1.2 to 2.3) °C | +3.7 (2.5 to 4.9) °C | +3.7 (2.5 to 4.9) °C |
| Warm days | 15 days | +20 (9 to 33) days | +32 (17 to 45) days | +57 (37 to 70) days | +57 (37 to 70) days |
| Warm nights | 14 days | +32 (21 to 53) days | +46 (32 to 67) days | +70 (59 to 79) days | +70 (59 to 79) days |
| **Rainfall** | | | | | |
| Total rainfall | 1,047 mm | +3 (-2 to +10) % | +5 (-6 to +17) % | +13 (-12 to +37) % | +13 (-12 to +37) % |
| Heavy-rainfall days | 14 days | +2 (-1 to + 5) days | +2 (-1 to +6) days | +4 (-2 to +13) days | +4 (-2 to +13) days |
| Consecutive dry days | 92 days | +4 (-11 to +15) days | +6 (-16 to +21) days | +11 (-11 to +31) days | +11 (-11 to +31) days |

This table shows the projected changes in 30-year averages, with respect to a present-day baseline of 1981-2010, for the '2030s' (2021-2050), the '2050s' (2035-2064), and the '2080s' (2071-2100). The average of gridded observations is also shown for 1981-2010 (note that since this is a grid-point average based on station observations, it will differ somewhat from values for a single station).

The average change is shown in each case together with an indication of the uncertainty range across the models (in brackets - the 90 per cent range). For temperature, the lower end of the range is always positive - indicating a robust pattern of change towards higher temperatures. For rainfall, the lower end of the range is negative, with larger positive changes at the upper end of the range. This indicates greater uncertainty in both the direction and magnitude of rainfall change than is the case for temperature.

For the 2030s and 2050s, only projections for the higher RCP8.5 emissions scenario are given. As the time series plots on the previous page show, there is very little difference between the two scenarios for the next couple of decades. By the 2080s, changes under the lower RCP2.6 emissions scenario (final column) are considerably reduced compared with the high-emissions scenario.

**Key messages and implications for climate change risk assessment of the Amaravati development**

- The climate of Amaravati is subject to large year-to-year variability. Thus, care is needed in interpreting local observational records which cover only a few years, and even in the absence of anthropogenic climate change, the city needs to be resilient to this natural variability.
- Observed records for the Amaravati region show emerging trends over the last few decades, in particular a clear trend towards higher temperatures and more frequent high-temperature extremes, with some indication of a tendency towards higher annual rainfall totals.
- Climate projections show a strengthening of the observed trends, particularly with higher greenhouse emissions, and a clearer tendency towards more intense and more frequent rainfall extremes.
- If global warming can be constrained to 2°C or less with respect to pre-industrial conditions, the impacts of climate change would be substantially reduced for Amaravati, particularly in the second half of the century.

| Projected climate changes | Potential impacts and risks |
|---|---|
| Warmer conditions, including more intense and more frequent high- temperature extremes and heat- wave days | • Human heat stress and other negative health effects, including potential increases in mortality, particularly if air quality also decreases<br>• Negative impacts and constraints on labour productivity, particularly on outdoor workers, including construction workers (especially during Phase 3 of the proposed Amaravati development)<br>• Potential increased demand for air conditioning, which would increase energy demand |
| Higher annual rainfall totals and more frequent/heavy-rainfall events | • Potential increase in flood risk<br>• Possible implications for water balance and for the quantity and quality of water resources (also taking into consideration the likely persistence of long dry spells and increased evaporation with warmer conditions) |

*Source:*
*Authors' analysis*

**Issues requiring further investigation:**

- The projections presented here focus on temperature and rainfall, but changes in other climate variables may also be relevant, e.g., changes in radiation and cloud cover may have implications for solar energy.
- The projections do not incorporate urban heat island effects. Will the planned green and blue spaces be sufficient to mitigate the development of an urban heat island effect which could further exacerbate the projected increases in high-temperature extremes?
- The projections are based on GCMs at a relatively coarse spatial scale. Would downscaled information, in particular from regional climate models, provide more reliable projections for the Amaravati area?

**Climate projections: Models, scenarios, and uncertainties**

The climate projections presented here are based on the output from global climate models (GCMs). These models represent the physical processes driving weather and climate at the grid-box level (typically at a resolution of a few hundred kilometres) using numerical equations and parameterisations in a similar way to the numerical weather prediction models from which they have evolved. They are forced by greenhouse gas emission or concentration pathways which reflect different assumptions about future socioeconomic and technological developments. Here, two Representative Concentration Pathways (RCPs) are used to span the range considered in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

- **RCP8.5:** a 'business as usual' high-emissions scenario, with concentrations of greenhouse gases by the end of the century that are almost four times pre-industrial levels. The expected rise in global mean temperature for RCP8.5 is similar to that projected for Amaravati at the end of the century.
- **RCP2.6:** effective national action and international cooperation limit carbon emissions to a lower pathway, which would keep the rise in global temperature compared with pre-industrial conditions to 2°C or lower (consistent with the goals of the 2015 Paris Agreement).

The reliability of GCMs can be assessed, in part, by considering how well they reproduce observations (using grid-box averages rather than point or station values to ensure a like-with-like comparison). Four available GCMs were excluded from this analysis due to their very low rainfall, particularly during the monsoon season. Assessment of the ~15 remaining models indicates that they simulate temperature extremes for the Amaravati region reasonably well, but tend to overestimate total rainfall. In all the time series plots shown here, a simple bias adjustment is used to bring models and observations into line over a baseline period of 1961-1990. For mean annual temperature, the adjustment factors required range from -0.2°C to +2.5°C across the models, with an average adjustment of +1°C. For total annual precipitation, ratios are used to make the adjustment, and range from 0.6 to 1.5, with an average value of 0.9 (indicating a 10 per cent overestimation on average by the models).

In addition to inevitable uncertainty about which emissions scenario will emerge in the future, there are inherent climate-modelling uncertainties associated with the response of the models to greenhouse gas forcing. Thus, it is good practice to use a number of models from different modelling centres, as has been done here, and to consider the range of responses (therefore, the 90 per cent range is shown on the time series plots) as well as the average multi-model ensemble response (thick line on the plots). This is particularly important for rainfall and especially rainfall extremes which tend to be more spatially and temporally variable than temperature.

For India and Amaravati, the monsoon is, of course, the major phenomenon of concern with respect to rainfall. The scientific literature on projected changes in monsoon systems, and more specifically their relevance for future change in regional climates, was assessed in the Fifth Assessment Report of the IPCC.

# Appendix B. Benefits of green infrastructure

## Benefits of green infrastructure as part of an adaptation plan

- **Increase collection capacity:** Reducing runoff volumes and rates through incorporation of green infrastructure within a service area decreases the overall flows into collection systems. This reduction of influent volumes can lower the frequency of combined sewer overflows and raw sewage backups as well as potentially reduce the need for infrastructure maintenance and expansion.

- **Increase resilience of service:** Facilitating groundwater recharge and reducing peak runoff flows may effectively reduce drought and flood-related service interruptions. Providing risk reduction through green infrastructure could improve the performance of other adaptation options to mitigate floods and droughts under projected climate conditions (e.g. combine rain gardens with stormwater storage to handle larger storms with current treatment capacity).

- **Enable incremental expansion of service:** Green infrastructure installations can be added as needed in areas that are not directly connected to existing infrastructure, in many cases, this decentralized approach allows for greater flexibility, faster implementation and lower costs than traditional grey infrastructure because it avoids building additional connections to the collection systems.

- **Decrease carbon footprint:** Implementing green infrastructure projects can reduce collection and treatment needs, thereby reducing the utility's associated energy demand and greenhouse emissions.

- **Leverage opportunities for co-benefits:** The costs of pursuing green infrastructure strategies may compare favorably to expanding or upgrading facilities when considering averted costs and additional benefits to the utility and larger community (e.g., air pollution reductions and fewer odor complaints). The longer-term benefits from green infrastructure projects may become more apparent when costs and impacts of different options are assessed across multiple economic dimensions (e.g., public services, public health and ecosystem services).

- **Improve public image:** Many green infrastructure projects provide aesthetic enhancement to communities, particularly when compared with expansion of the built environment. Successful projects can make communities more attractive, increase property values, increase public safety and serve as visible reminders that a utility is pursuing adaptation holistically.

*Source:*
*Authors' analysis*

# Appendix C. Benefits of water demand management

## Benefits of water demand management as part of an adaptation plan

- **Increase operational flexibility and resilience of service:** Sustainable use of existing water resources can reduce risks related to projected decreases in water supply and increases in service demand. Water conservation reduces the need to develop new source water supplies or to expand the infrastructure at water and waste water facilities. Water efficiency and conservation programs can preserve natural resources and increase the sustainability of water supplies, leaving more water for future use and improving the ambient water quality and aquatic habitat.

- **Cost savings and opportunity to reinvest:** More efficient use of water often reduces operating and treatment costs, resulting in a net savings which can be reinvested to help address the other challenges - such as the need for rate increases, the need to address gaps in funding or can be used to support additional adaptation efforts. When faced with potential water shortages, developing and implementing water efficiency and conservation measures almost always involves a lower cost than developing a new water source or expanding water or waste water infrastructure to meet demand or other goals.

- **Deferred and avoided capital investments:** Water demand management practices will often allow the utility to continue to meet water demand without needing to expand existing facilities or build new facilities. Water demand management can also extend the life of existing facilities.

- **Maintain environmental benefits of water resources:** Reduced water consumption helps to maintain the reservoir water levels and groundwater tables, and supports the use of lakes, rivers and streams for recreation and wildlife. When use of these resources reduces surface or groundwater levels, natural and human pollutant levels can increase and threaten human and ecological health. Using water more efficiently helps maintain supplies at safe levels, protecting human health and the environment.

- **Decrease carbon footprint:** The delivery of water requires energy to pump, treat and distribute water. End users also use energy to heat water for certain uses. Implementing water efficiency and conservation projects can reduce the amount of water withdrawals from sources and demand on waste water services, thereby reducing energy needs and associated greenhouse gas emissions. Use of more water efficient products by customers can also decrease energy needed to heat water.

- **Improve public image:** Communicating utility actions to increase water efficiency and encouraging water conservation practices to customers can establish a utility as a steward of local water resources and a leader in pursuing financially and socially responsible actions.

*Source:*
*Authors' analysis*

# Appendix D. Electricity consumption data for Vijayawada

CATEGORY WISE POWER CONSUMED AND DEMAND PER YEAR AND PER DAY FOR CRDA VILLAGES FOR THE FY 2015-2016

| MANDAL | Village/ULB | LT CATEGORY-1 | | | | LT CATEGORY-2 | | | | LT CATEGORY-3 | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Power Consumed in the FY | Units in MU | Demand per year | Demand per day | Power Consumed in the FY | Units in MU | Demand per year | Demand per day | Power Consumed in the FY | Units in MU | Demand per year | Demand per day | |
| | GANGAVALLI | 59073 | 0.059073 | 2.658285 | 0.00728 | 8952 | 0.008952 | 0.40284 | 0.0011 | 17736 | 0.017736 | 0.79812 | 0.00219 | |
| | GOPINENIPALEM | 440614 | 0.440614 | 19.82763 | 0.05432 | 6617 | 0.006617 | 0.29776 | 0.00082 | 12131 | 0.012131 | 0.545895 | 0.0015 | |
| | INDUGAPALLI | 183000 | 0.183 | 8.235 | 0.02256 | 1953 | 0.001953 | 0.08788 | 0.00024 | 5638 | 0.005638 | 0.25371 | 0.0007 | |
| | KAKARAVAI | 214712 | 0.214712 | 9.66204 | 0.02647 | 1684 | 0.001684 | 0.0757 | 0.00021 | 711 | 0.000711 | 0.031995 | 0.00009 | |
| | KANNEVEDU | 255437 | 0.255437 | 11.49467 | 0.03149 | 9341 | 0.009341 | 0.42034 | 0.00115 | 20270 | 0.02027 | 0.91215 | 0.0025 | |
| | KHAMBAMPADU | 812729 | 0.812729 | 36.57281 | 0.1002 | 96122 | 0.096122 | 4.32549 | 0.01185 | 26377 | 0.026377 | 1.186965 | 0.00325 | Rebbavaram Village included in Khambampadu (V) |
| | LINGALA | 309902 | 0.309902 | 13.94559 | 0.03821 | 8191 | 0.008191 | 0.368595 | 0.00101 | 12254 | 0.012254 | 0.55143 | 0.00151 | |
| | M.CH.PALEM | 204732 | 0.204732 | 9.21294 | 0.02524 | 4643 | 0.004643 | 0.208935 | 0.00057 | 0 | 0 | 0 | 0 | |
| | MAKKAPET | 776001 | 0.776001 | 34.92005 | 0.09567 | 148733 | 0.148733 | 6.692985 | 0.01834 | 18451 | 0.018451 | 0.830295 | 0.00227 | |
| | MANGOLLU | 589712 | 0.589712 | 26.53704 | 0.0727 | 25376 | 0.025376 | 1.14192 | 0.00313 | 21142 | 0.021142 | 0.95139 | 0.00261 | |
| | P.M.PALLI | 196212 | 0.196212 | 8.82954 | 0.02419 | 2017 | 0.002017 | 0.090765 | 0.00025 | 8435 | 0.008435 | 0.379575 | 0.00104 | |
| | POCHAVARAM | 84514 | 0.084514 | 3.80313 | 0.01042 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | POLAMPALLI | 482981 | 0.482981 | 21.73415 | 0.05955 | 44536 | 0.044536 | 2.00412 | 0.00549 | 33184 | 0.033184 | 1.49328 | 0.00409 | |
| | TALLURU | 223322 | 0.223322 | 10.04949 | 0.02753 | 1700 | 0.0017 | 0.0765 | 0.00021 | 0 | 0 | 0 | 0 | |
| | VATCHAVAI | 2200790 | 2.20079 | 99.03555 | 0.27133 | 361314 | 0.361314 | 16.25913 | 0.04455 | 114335 | 0.114335 | 5.145075 | 0.0141 | |
| | VEMAVARAM | 304922 | 0.304922 | 13.72149 | 0.03759 | 2808 | 0.002808 | 0.12636 | 0.00035 | 8905 | 0.008905 | 0.400725 | 0.0011 | |
| | VEMULANARVA | 201140 | 0.20114 | 9.0513 | 0.0248 | 1369 | 0.001369 | 0.061605 | 0.00017 | 0 | 0 | 0 | 0 | |
| | HASANBADA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| **VATCHAVAI Total** | | **9533532** | **9.533532** | **429.0089** | **1.17537** | **972385** | **0.972385** | **43.75733** | **0.11988** | **352498** | **0.352498** | **15.86241** | **0.04346** | |
| Vijayawada (R) | AMBAPURAM | 829943 | 0.829943 | 37.34744 | 0.10232 | 84892 | 0.084892 | 3.82014 | 0.01047 | 149816 | 0.149816 | 6.74172 | 0.01847 | |
| | ENIKEPADU | 4686820 | 4.68682 | 210.9069 | 0.57783 | 1774140 | 1.77414 | 79.8363 | 0.21873 | 598801 | 0.598801 | 26.94605 | 0.07382 | |
| | GOLLAPUDI | 15568617 | 15.56862 | 700.5878 | 1.91942 | 4440788 | 4.440788 | 199.8355 | 0.54749 | 1477882 | 1.477882 | 66.50469 | 0.1822 | |
| | GUDAVALLI | 877744 | 0.877744 | 39.49848 | 0.10822 | 554647 | 0.554647 | 24.95912 | 0.06838 | 47027 | 0.047027 | 2.116215 | 0.0058 | |
| | JAKKAMPUDI | 3471356 | 3.471356 | 156.211 | 0.42798 | 368809 | 0.368809 | 16.59641 | 0.04547 | 85816 | 0.085816 | 3.86172 | 0.01058 | |
| | K.T.PALLI | 1296293 | 1.296293 | 58.33319 | 0.15982 | 178752 | 0.178752 | 8.04384 | 0.02204 | 127187 | 0.127187 | 5.723415 | 0.01568 | |
| | NIDAMANURU | 3941449 | 3.941449 | 177.3652 | 0.48593 | 1056215 | 1.056215 | 47.52968 | 0.13022 | 467468 | 0.467468 | 21.03606 | 0.05763 | |
| | NUNNA | 6217671 | 6.217671 | 279.7952 | 0.76656 | 1309539 | 1.309539 | 58.92926 | 0.16145 | 999721 | 0.999721 | 44.98745 | 0.12325 | |
| | NYNAVARAM | 835665 | 0.835665 | 37.60493 | 0.10303 | 83821 | 0.083821 | 3.771945 | 0.01033 | 67118 | 0.067118 | 3.02031 | 0.00827 | |
| | PATAPADU | 504210 | 0.50421 | 22.68945 | 0.06216 | 48787 | 0.048787 | 2.195415 | 0.00601 | 50625 | 0.050625 | 2.278125 | 0.00624 | |
| | PRASADAMPADU | 11180334 | 11.18033 | 503.115 | 1.3784 | 1174747 | 1.174747 | 52.86362 | 0.14483 | 163477 | 0.163477 | 7.356465 | 0.02015 | |
| | PYDURIPADU | 588523 | 0.588523 | 26.48354 | 0.07256 | 10769 | 0.010769 | 0.484605 | 0.00133 | 0 | 0 | 0 | 0 | |
| | RAMAVARAPPADU | 14808014 | 14.80801 | 666.3606 | 1.82565 | 1552573 | 1.552573 | 69.86579 | 0.19141 | 14400 | 0.0144 | 0.648 | 0.00178 | |
| | RAYANAPADU | 1289433 | 1.289433 | 58.02449 | 0.15897 | 247011 | 0.247011 | 11.1155 | 0.03045 | 321859 | 0.321859 | 14.48366 | 0.03968 | |
| | SHABADA | 202997 | 0.202997 | 9.134865 | 0.02503 | 2581 | 0.002581 | 0.116145 | 0.00032 | 0 | 0 | 0 | 0 | |
| | VEMAVARAM | 135485 | 0.135485 | 6.096825 | 0.0167 | 17789 | 0.017789 | 0.800505 | 0.00219 | 17120 | 0.01712 | 0.7704 | 0.00211 | |

CATEGORY WISE POWER CONSUMED AND DEMAND PER YEAR AND PER DAY FOR CRDA VILLAGES FOR THE FY 2015-2016

| MANDAL | Village/ULB | LT CATEGORY-1 | | | | LT CATEGORY-2 | | | | LT CATEGORY-3 | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Power Consumed in the FY | Units in MU | Demand per year | Demand per day | Power Consumed in the FY | Units in MU | Demand per year | Demand per day | Power Consumed in the FY | Units in MU | Demand per year | Demand per day | |
| | TADEPALLI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Belongs to Guntur District. |
| | DONI ATHKURU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | De-Populated Village. |
| **Vijayawada (R) Total** | | **66434554** | **66.43455** | **2989.555** | **8.19056** | **12905860** | **12.90586** | **580.7637** | **1.59113** | **4588317** | **4.588317** | **206.4743** | **0.56568** | |
| Vijayawada (U) | VIJAYAWADA ULB | 566243057 | 566.2431 | 25480.94 | 69.81079 | 182145624 | 182.1456 | 8196.553 | 22.45631 | 25503894 | 25.50389 | 1147.675 | 3.14432 | |
| **Vijayawada (U) Total** | | **566243057** | **566.2431** | **25480.94** | **69.81079** | **182145624** | **182.1456** | **8196.553** | **22.45631** | **25503894** | **25.50389** | **1147.675** | **3.14432** | |
| VUYYURU | PEDA OGIRALA | 1016876 | 1.016876 | 45.75942 | 0.12537 | 75888 | 0.075888 | 3.41496 | 0.00936 | 5408 | 0.005408 | 0.24336 | 0.00067 | |
| **VUYYURU Total** | | **1016876** | **1.016876** | **45.75942** | **0.12537** | **75888** | **0.075888** | **3.41496** | **0.00936** | **5408** | **0.005408** | **0.24336** | **0.00067** | |
| **Grand Total** | | **841593046** | **841.593** | **37871.69** | **103.7581** | **233566513** | **233.5665** | **10510.49** | **28.79587** | **66277933** | **66.27793** | **2982.507** | **8.17125** | |

*Source:*
*Authors' analysis*

Total electricity consumption: 1,141.5 Million KWhr

# Appendix E. Per capita electricity consumption @ 6 per cent growth rate for Amaravati

| Year | Per capita electricity consumption (KWhr) |
|---|---|
| 2016 | 902 |
| 2017 | 956 |
| 2018 | 1,013 |
| 2019 | 1,074 |
| 2020 | 1,139 |
| 2021 | 1,207 |
| 2022 | 1,280 |
| 2023 | 1,356 |
| 2024 | 1,438 |
| 2025 | 1,524 |
| 2026 | 1,615 |
| 2027 | 1,712 |
| 2028 | 1,815 |
| 2029 | 1,924 |
| 2030 | 2,039 |
| 2031 | 2,162 |
| 2032 | 2,291 |
| 2033 | 2,429 |
| 2034 | 2,575 |
| 2035 | 2,729 |
| 2036 | 2,893 |
| 2037 | 3,066 |
| 2038 | 3,250 |
| 2039 | 3,445 |
| 2040 | 3,652 |
| 2041 | 3,871 |
| 2042 | 4,104 |
| 2043 | 4,350 |
| 2044 | 4,611 |
| 2045 | 4,887 |
| 2046 | 5,181 |
| 2047 | 5,491 |
| 2048 | 5,821 |
| 2049 | 6,170 |
| 2050 | 6,540 |

*Source:*
*Authors' analysis*

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Relief features of the Dhyana Buddha sculpture at Amaravati.

Image: iStock

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