Making Madhya Pradesh's Smart Cities Climate Resilient

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

Report | January 2020

Extremes of rainfall under a changing climate will cause enormous damage to infrastructure, lives and livelihoods. Anticipating these impacts, and preparing for the same, is vital.

Image: iStock

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CEEW-University of East Anglia-Mott MacDonald Report
January 2020
ceew.in

Suggested citation: Goodess, Clare, Colin Harpham, Nikki Kent, Ramesh Urlam, Sushma Chaudhary and Hem H. Dholakia. 2020. *Making Madhya Pradesh's Smart Cities Climate Resilient*. New Delhi: Council on Energy, Environment and Water.

Cover image: iStock.

Peer reviewers: Bhushan Kankal, Science Officer, Global Centre for Energy and Environment, Ahmedabad University; Dr Avijit Khanra, Assistant Professor, Department of Industrial Management and Engineering, Indian Institute of Technology - Kanpur; and Simon Lucas and Aloke Barnwal from Foreign and Commonwealth Office (FCO).

Publication team: Alina Sen (CEEW), Mihir Shah (CEEW), Nishtha Vishwakarma, Malini Sood, Twig Designs, and Friends Digital.

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Acknowledgments

This report was made possible by the unwavering support of multiple stakeholders in the Government of Madhya Pradesh. We are especially grateful to Shri Vivek Aggarwal, Commissioner, Urban Administration and Environment Directorate and his team, for their support. Further, we received pertinent inputs, timely feedback, and constructive comments from the CEOs of the different Smart Cities of Madhya Pradesh. We extend our gratitude to Mr Chandramauli Shukla, Mr Rohan Saxena, Mr Gajendra Singh, and Ms Bidisha Mukherjee.

The report was made possible through funding from the Prosperity Fund and the Foreign and Commonwealth Office, UK. We extend our heartfelt thanks to Mr Simon Sharpe, Mr Simon Lucas, Mr Aloke Barnwal, Ms Anu Sareen, Mr Yash Mehra, Mr Nakul Sharma, Mr Siddharth Chatpalliwar, and Mr Naren Pasupalati.

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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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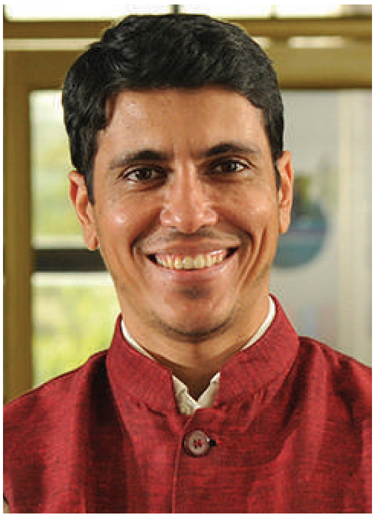
Sushma Chaudhary has a consolidated work experience of over 20 years as Infrastructure Specialist in the field of infrastructure projects. Being a Civil Engineer by qualification, and with post-graduation in Construction and Project Management, her core competence has been in multi-disciplinary large-scale 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 formerly led the Risks and Adaptation portfolio at 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.

Image: iStock

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Abbreviations

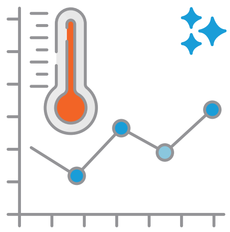
ABD	area-based development
BRT	bus rapid transit
CCTV	closed circuit television
CMIP5	Coupled Model Inter-comparison Project 5
FCO	Foreign and Commonwealth Office
GCM	General Circulation Model
ECS	equivalent car space
IPCC	Intergovernmental Panel on Climate Change
HadEX2	Met Office Hadley Centre, UK
HFL	high flood level
ICT	Information and Communication Technology
IMD	Indian Meteorological Department
LRT	light rail transit
MLD	millions of liters per day
MP	Madhya Pradesh
MSW	municipal solid waste
Ptotal	total rainfall
PPP	public private partnership
R20 mm	heavy-rainfall days
SDG	Sustainable Development Goals
STP	sewage treatment plant
Tmean	mean temperature
TN90p	warm nights
TX90p	warm days
WSDI	heat-wave days (Warm Spell Duration Indicator)

India is going through a construction boom. Careful selection of materials and design thinking can mitigate energy use in the building sector as well as build resilience to climate change.

Image: iStock

Executive summary

Building cities requires large investments in infrastructure that encompasses physical assets, functions, and systems. There is increasing recognition that infrastructure and related sectors are at risk due to climate change. Madhya Pradesh has embarked on creating a smart urban future. This presents opportunities for building Smart Cities across Madhya Pradesh to mainstream climate resilience into their Smart City Plans.



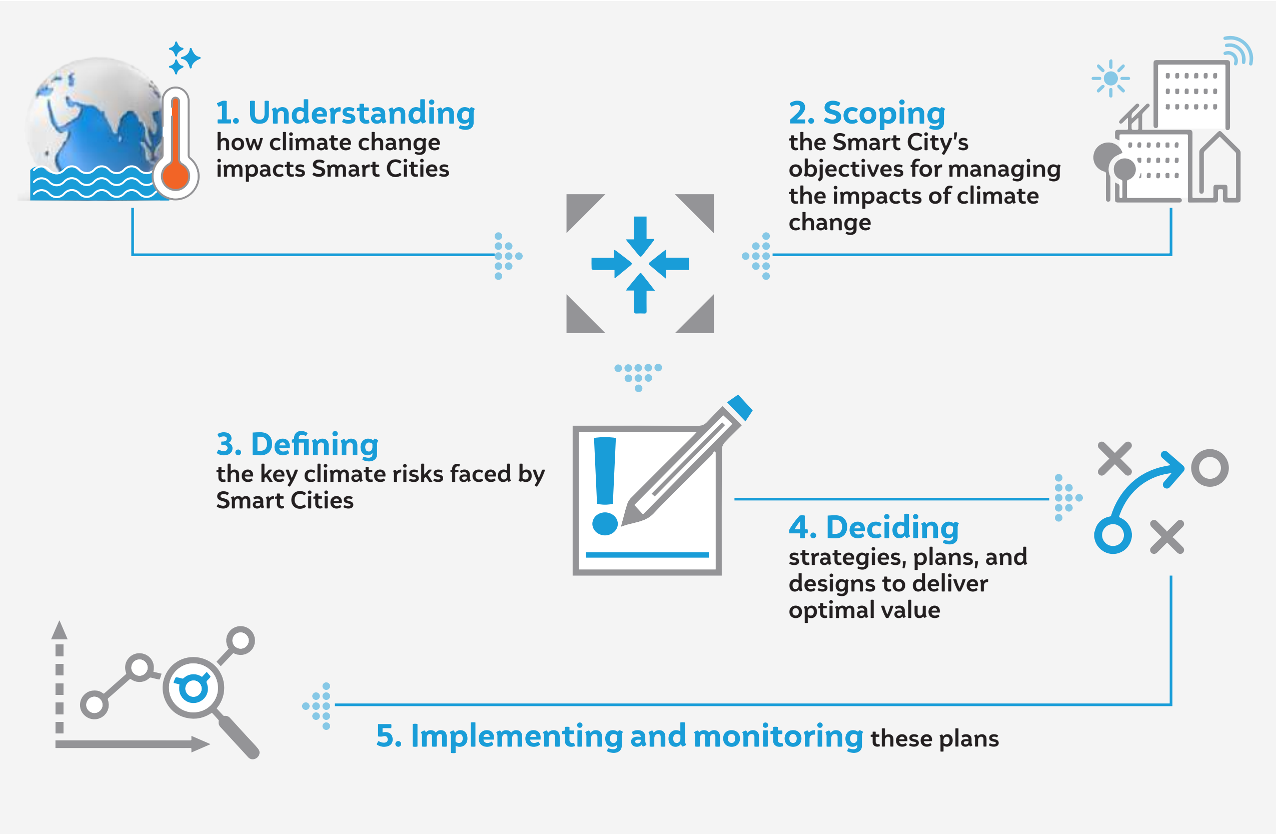
Data from climate models suggest that by the middle of the century, temperatures are likely to increase by about 1.3°C in Indore and by about 1.5°C in Gwalior compared to current levels

Smart Cities across Madhya Pradesh need 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 1.3°C in Indore and by about 1.5°C in Gwalior compared to current levels. Further, average rainfall is likely to increase across all Smart Cities (Bhopal ~8 per cent; Gwalior~3 per cent; Indore ~10 per cent) by the middle of the century. Days with extreme heat (i.e. heat-wave days) as well as heavy-precipitation events are likely to become more frequent. These changes may place infrastructure such as energy, transport, and water supply at considerable risk.

Opportunities exist to plan infrastructure such as waste, sanitation, and water supply that can withstand climate impacts; a long lifetime, design, and material considerations make infrastructure vulnerable. Potential impacts of climate change on infrastructure may include: risk of fire in and around landfills (in extremely hot conditions); damage to sanitation-and water-related infrastructure; and compromised integrity of roads and pavements. Further, the interconnected nature of infrastructure implies that interdependencies need to be mapped and addressed. Regular risk assessments, adoption of better technical standards, use of resilient materials, and creation of innovative financial instruments are some of the opportunities available to reduce vulnerability.

The financial impacts of climate risks on infrastructure may be substantial. Although an assessment of the impacts on specific projects across infrastructure sectors was beyond the scope of this study, it has been well established that climate change can have drastic economic consequences. Typically, climate-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 resulting from extreme events through suitable insurance mechanisms. It would be prudent to plan for these additional investments to protect infrastructure from climate change.

Smart Cities across Madhya Pradesh have commenced efforts to develop a climate-resilience roadmap. For instance, a climate risk assessment for Indore has been carried out.
A comprehensive climate roadmap involves five building blocks as presented below.



This framework can be tailored to the specific needs, objectives, and local contexts of Smart Cities in Madhya Pradesh.

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

- Prioritise and undertake a climate screening assessment of critical infrastructure such as energy, metro system, roads, and water supply.
- Create plans based on trade-offs between system design and costs after factoring in information about future climate change and economic considerations.
- Define the level of risk that the city is prepared to bear or the extent to which it is willing to build resilience, and implement appropriate resilience options to mitigate these risks.
- Assign ownership and responsibility alongwith timeframes for reporting progress in the adoption of resilience measures.
- Undertake periodic review and reporting of risks as well as of progress on the preparation and implementation of resilience plans.

1. Introduction

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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 a 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.[1] 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.

1. Planning Commission (2012). Twelfth Five Year Plan 2012-2017. Government of India. Available at http://planningcommission.nic.in/plans/planrel/fiveyr/welcome.html

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 manifested and 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 risks and impacts.

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

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 >2°C by the end of the century.[2] Projected increases in precipitation may cause enormous damage to infrastructure such as bridges, roads, buildings, communications, and health facilities. These projected climate changes are expected to greatly impact 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[2]. 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—like the Asian Cities Climate Change Resilience Network,[3] 100 Resilient Cities,[4] and C40 Cities Climate Leadership Group[5]—are moving to setup, equip, support, collaborate, and exchange knowledge on how to increase city resilience to climate change.

Complementary support in the form of policies, regulations, and improved building and infrastructure design codes that enforce or mandate designing guidelines to meet higher thresholds for temperature and precipitation are needed at both national and state levels. In this regard, Indian cities are already taking appropriate action to increase the resilience of their infrastructure to meet the demands of future climate change.

Preparing for and investing in building resilience will allow Indian cities to both grow sustainably and to attract investment, companies, and skilled people, thereby giving them a competitive edge, both nationally and internationally. For Smart Cities such as Bhopal, Indore, Ujjain, Gwalior, and Jabalpur, this presents an opportunity to mainstream climate resilience into their individual city development plans. It allows an opportunity to consider sectoral climate risks, their interaction, and their macroeconomic and distributional impacts, as well as address institutional barriers to building adaptive capacity. In achieving these goals, it allows for setting up systems to capture relevant data, to institute risk management processes, and to design pertinent decision-making tools.

Preparing for and investing in building resilience will allow Indian cities to grow sustainably and to attract investment, companies, and skilled people

2. Garg A et al. (2016). Climate Change and India: Adaptation Gap 2015. Available at http://ceew.in/pdf/CEEW-IIMA-%20IITGn-Adaptation-Gap-Report%2030Nov15.pdf Last Accessed 16 November 2017

3. https://www.acccrn.net/

4. http://www.100resilientcities.org/

5. http://www.c40.org/

2. Methodology

Image: iStock

We adopted a two-step approach for understanding climate risks. The first step involved projecting temperature and precipitation for these cities under future climate scenarios. We then connected these transitions with smart-city plans to develop a risk profile.

2.1 Developing climate change risk profiles for Madhya Pradesh Smart Cities

To provide an overview to city stakeholders of the future climate risks faced by their particular Smart City, as well as provide a basis for the sector-specific Smart City Proposal review (Section 3), the climate resilience framework and the roadmap (Section 4), the first step was to produce a climate change risk profile for each of the Madhya Pradesh Smart Cities (Bhopal, Gwalior, Indore, Jabalpur, and Ujjain). Since a major purpose of these profiles was to promote awareness and to provoke thought and discussion among Smart City stakeholders, it was agreed to produce them as free-standing, relatively brief (four-page) documents, written as far as possible in non-technical language to make them accessible to a broad audience. These risk profiles are given (as provided to Smart City stakeholders) in Annexures A–E. They focus 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 annexure of each risk profile, the projections up to 2100 were developed using output from CMIP5 global climate models (GCMs Initially, 18–20 models (depending on the climate variable) were used (see Table 1).

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	128 x 256	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 for the particular grid box in which each Smart City is located. This resolution was used to ensure consistency with the CRU-TSv.3.22 dataset (Harris et al., 2014).[6] 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 (HadEX2) (Donat et al., 2013),[7] which provides coverage from 1901 or 1951 to 2010 together with the processed CMIP5 model output (Sillman et al., 2013 a; Sillman et al., 2013b).[8] Gridded observations were used to ensure consistency with the grid-box output of the climate models. In all cases, output was extracted for the particular grid box in which each Smart City is located. To indicate how these gridded observations relate to local conditions, annual/monthly station data for the city (from the neighbouring city of Indore in the case of Ujjain) are also shown on some plots.

Climate models are not perfect. Thus, a simple bias adjustment procedure was used to bring models and observations into line over a baseline period of 1961–1990. These adjustments were applied to the future on the assumption that the model errors are 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. For rainfall, these plots revealed four models that performed very poorly, with very low rainfall compared to recorded observations and with no strong monsoon season.

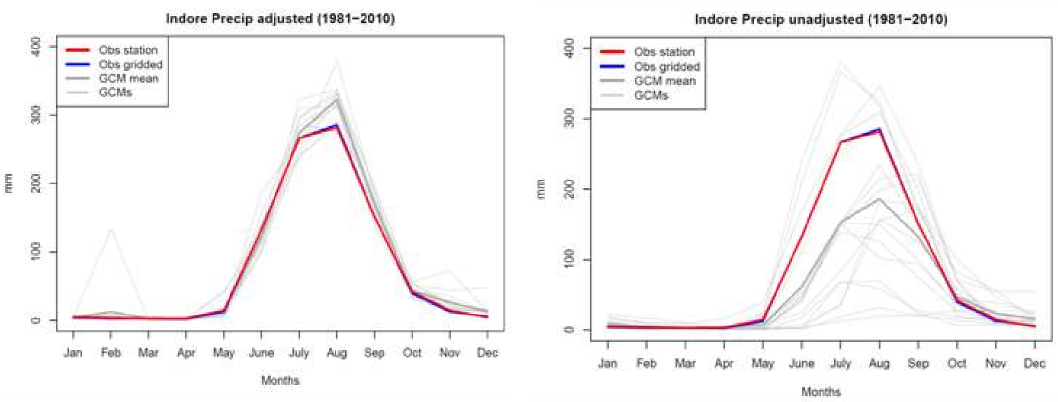


Figure 1
Seasonal cycle of monthly observed gridded (blue), observed station (red), and simulated (grey) total rainfall for Indore

Source: Authors' analysis

Making the necessary adjustments to these models would artificially inflate their projected changes. Thus, these four models were excluded (see Table 1) and only the remaining models were adjusted (Figure 1) and used.

Figure 1. Seasonal cycle of monthly observed gridded (blue), observed station (red), and simulated (grey) total rainfall for Indore. Left-hand side: unadjusted output from 19 climate models. Right-hand side: adjusted output from 15 climate models.

6. I. Harriset al. (2014) "Updated high-resolution grids of monthly climatic observations: The CRU TS3.10 Dataset," International Journal of Climatology 34: 623–642.doi:10.1002/joc.3711

7. M. G. Donat et al. (2013) "Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset," Journal of Geophysical Research-Atmospheres 118: 2098–2118.doi:10.1002/jgrd.50150

8. J. Sillmann et al. (2013a) "Climate extremes indices in the CMIP5 multimodel ensemble: Part 1. Model evaluation in the present climate," Journal of Geophysical Research-Atmospheres 118: 1716–1733.doi:10.1002/jgrd.50203

J. Sillmann et al. (2013b) "Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections," Journal of Geophysical Research-Atmospheres 118: 2473–2493.doi:10.1002/jgrd.50188

The first two pages of each risk profile provide 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 a number of indices of extremes are also provided (Table 2). 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).

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 > 90th percentile	Day
TX90p	Warm days	Number of days when TX > 90th percentile	Day
WSDI	Heat-wave days (Warm Spell Duration Indicator)	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Day
R20mm	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 < 1mm)	Day

Table 2
Definitions of climate indices, including indices of extremes, used in the climate change risk profile.

TN: minimum temperature.
TX: maximum temperature.

Source: Authors' analysis

The third page of each risk profile lists:

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

Finally, an Appendix 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.

2.2 Connecting climate data to city plans

Following initial discussions with the Foreign and Commonwealth Office (FCO) and MP Smart City officials on identifying their key concerns related to climate risks for Indian cities, a review of the three MP Smart Cities was carried out. A review of the Smart City proposals and documentation on selected important sectors for each city was conducted for Indore, Bhopal, and Jabalpur. These reviews undertook an initial climate screening assessment based on the available literature, and on the Smart City Proposals. The sector has done the following:

- Looked at how the projected changes in temperature and rainfall could affect the sectors in question and the Smart City Proposal development plans.
- Focused on a series of key climate considerations for the three MP cities in the context of the Smart City Proposals and beyond.
- Compiled and identified relevant sector-specific recommendations for climate resilience in a roadmap over different timescales where possible.

In addition to the sector reviews, an Indian Cities Resilience Framework was developed. This was built on the Mott MacDonald Climate Resilience Framework. This framework has been applied to a number of projects across a wide range of sectors and international good practices that are being used and tested by European, Asian, and international city networks such as the Covenant of Mayors, the Asian Cities Climate Change Resilience Network, 100 Resilient Cities, and the World Bank Decision Tree Framework. We revised the Indian Cities Resilience Framework such that it could be applied to MP Smart Cities. To enable the integration of the framework into city planning and policy making, an overarching roadmap has been proposed along with recommendations for short- to longer-term priority actions, as well as a draft text for inclusion in contracts and Terms of Reference when commissioning development work.

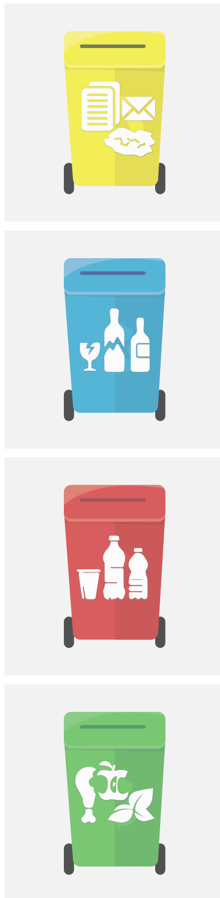
As extreme rainfall events become frequent, investing in adequate stormwater drains will be critical to mitigating flooding events.

Image: iStock

3. Opportunities to mainstream climate resilience in Smart City plans

This chapter discusses the opportunities to mainstream climate resilience in smart-city plans for solid-waste, transport and sanitation sectors.

3.1 Solid waste management



We discuss the existing scenario, potential impacts due to climate change as well as possible solutions for the solid-waste sector.

Existing scenario

Growing population and changing consumption patterns have made the management of solid waste a priority issue across different cities in Madhya Pradesh. Hence, all Smart City Plans recognise the need to proactively manage solid waste. For instance, Indore generates about 1,100 tons/day[9] of municipal solid waste (MSW). Of this, only 76 per cent of the waste is collected by local authorities. As solid-waste-related issues become more acute, Smart Cities have identified potential challenges (general as well as city-specific) in the management of waste:

- Poor public participation in waste segregation.
- Poor efficiency of waste collection.
- Inadequate maintenance of transport fleet, including underutilisation of capacity.
- Inadequate siting and mismanagement of landfills – not properly covered, no ring fencing to prevent entry by people and animals.
- Lack of financial resources for hiring adequate manpower, upgrading vehicle fleet, and adopting recycling technology.
- Illegal dumping of industrial waste at landfill sites[10] in Bhopal.

9. Smart City Plan – Indore, 2015. Available at http://www.smartcityindore.org/ Last accessed16 November

10. R. S. Parihar et al. (2016) "A review on municipal solid waste collection of Bhopal city," International Journal of Scientific Engineering and Technology, 5(5); 259–263

	Indore	Bhopal	Jabalpur
Waste generation (tons/day)	1,100	800	450
Collection efficiency	76%	85%	88%
Management			
Waste to energy (TPD)	500	NA*	600 tons generate power of 11.5 MW.[11]
Landfill		• Landfill near Bhanpur. • Private dumping near Jamuri Maidan.	NA*
Smart City Proposals	100% segregation and collection.	• Integrated solid waste management (SWM) using public-private partnership (PPP) approach. • Transfer stations and bio-methanation plants under construction. • 100% segregation and collection. • New site being developed at Adampur Chhawni.	• Use of information and communication technology (ICT) in SWM. • Creation of 'Apna Nigam' mobile app for citizen participation through geo-tagging of issues and quick grievance redressal. • Adequate investments made in waste collection infrastructure.

Table 3
Comparison of solid waste management across cities

*NA - Not available in the Smart City Plan

Source: Compiled by authors based on a review of Smart City plans. We include all stages of SWM, from collection to transportation and disposal of refuse, across all cities have been reviewed with respect to climate change

Possible impacts due to a changing climate

It is highly likely that future climate change will have an impact on the overall management of solid waste in Smart Cities in Madhya Pradesh. Changes in temperature and precipitation will have a severe impact on all stages of waste management, from collection to disposal. The potential impacts are listed in Table 4.

11. Jabalpur Municipal Corporation (2005). Improved Solid Waste Management in Jabalpur. Available at http://www.umcasia.org/uploads/Citylinks_Jabalpur_case_study_Improved_solid_waste_management_in_Jabalpurpdf.pdf Last accessed 16 November 2017

Table 4
Possible climate risks for the waste sector
Source: Authors' analysis

Particulars[12]	Collection	Waste to energy plant	Disposal
Temperature Change	• Impact on efficiency of solid waste collection system. • Increased odour and pest activity, requiring more frequent waste collection. • Overheating of collection vehicles, requiring additional cooling capacity, including to extend engine life.	Clear effect of outdoor ambient air temperature on electricity production of a steam-condensing turbine-generator set coupled with an air condenser.	• Altered decomposition rates. • Increased risk of fire at disposal sites.
	Greater exposure of workers to flies, which are a major cause of infectious diseases (flies breed more quickly in warm temperatures and are attracted to organic waste).		
Particulars[12]	**Collection**	**Waste to energy plant**	**Disposal**
Precipitation Change	• Flooding of collection routes and access roads to landfills, making them inaccessible. • Increased stress on collection vehicles and workers as a result of waterlogged waste.	Change in temperature, cloud cover, rainfall pattern, and wind speed, all factors that could impact future waste-to-energy facilities.	• Increased flooding in and around sites. • Increased leachate that needs to be collected and treated. • Potential risk of fire if conditions become too dry and too hot.
Extreme wind	Reduced access to collection facilities and to access routes to landfills due to damage and debris.		

Recommendations for solid waste management from the climate change perspective

Intelligent SWM has been proposed under the pan-city solution with a focus on improving the operational efficiency for collection, transportation, landfill management, and waste-to-energy processing. The following are the key components proposed under the Smart City Proposals (SCP):

- Provision of citizen services through mobile-based apps
- GIS-based asset management
- Supervision and monitoring of weigh bridge and waste-processing facilities

The above components will help the local authorities to improve the efficiency of the current system, but may not be enough to mitigate or minimise climate risks. To address issues of SWM, new infrastructure is required and much of the existing infrastructure needs to be upgraded. For any new waste facility, increased resilience to climate and weather effects can be built into the planning process.

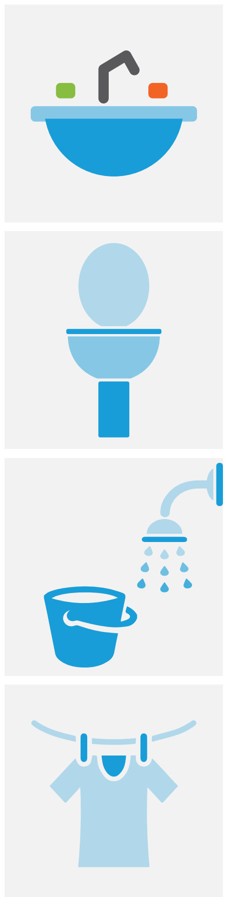
The key recommendations for climate-resilient solid waste infrastructure are grouped into two categories, i.e. at the planning or policy level and at the implementation level. They are set out in Table 5.

12. Committee on Climate Change (2017).UK Climate Change Risk Assessment 2017: Evidence Report. Available at https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/uk-climate-change-risk-assessment-2017/ Last accessed 16 November 2017

Table 5
Key recommendations[13] for the waste management sector

Source: Authors' analysis

Planning, policy changes, and project development
• Site landfills away from floodplains, wetlands, or areas with high water tables. • Site landfills away from sources of drinking water supply. • Develop sites large enough to accommodate projected population growth and corresponding amounts of waste generation. • Design sites with sorting, recycling, and composting facilities. • Update design standards to elevate and strengthen containment walls to accommodate future climate risks. • Design water catchment systems that can keep pace with projected rainfall patterns. • Plan for secure landfill closure and/or relocation.
Construction, operation and maintenance, and programme activities
• Increase financial and technical resources for more frequent maintenance and repair of SWM transport infrastructure. • Train waste sorters and educate the public about the need for separating recyclable and compostable material from other waste. • Regularly inspect the integrity of water catchment systems and containment walls, particularly following extreme-rain or storm events. • Continue to monitor landfills for groundwater contamination and cover erosion.



3.2 Sanitation

It is well understood that access to sanitation services and water supply plays an important role in poverty alleviation and health protection.[14] Smart Cities recognise the importance of providing these services to citizens. Climate change impacts that are manifested through the water sector will likely disrupt sanitation services. Therefore, there is a need to anticipate potential climate risks and to actively plan for sanitation-related services at the city level. We review some of the unique challenges for Indore, Bhopal, and Jabalpur with respect to sanitation-related services and potential climate risks.

Indore

Indore lies on the Saraswati and Khan rivers, on an elevated plain, with the Vindhyachal range to the south. As per the Indore SCP, Indore does not have any decentralised waste treatment plant at present. The city has two existing sewage treatment plants (STPs), which are connected by primary city sewers. There are decentralised individual STPs in some of the privately owned plots and group housing projects in suburban areas. The treated sewage is not being reused or recycled. It is being discharged into the Khan River, whose waters are being used for irrigation in the downstream hinterland. The issues that have been identified with respect to sanitation are:

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13. USAID (2012). Solid Waste Management: Addressing Climate Change Impacts on Infrastructure: Preparing for Change. Available at https://www.climatelinks.org/resources/addressing-climate-change-impacts-infrastructure-preparing-change-solid-waste-management. Last accessed 16 November 2017

14. N. Oates et al. (2014). Adaptation to Climate Change in Water, Sanitation and Hygiene. Overseas Development Institute. Available at https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8858.pdf; accessed 25 April 2017.

- Inadequate capacity to treat sewage. Indore generates around 245 million litres per day (MLD) of sewage. However, only 90 MLD (36.72 per cent) reaches the existing STPs. The STP at Kabitkhedi, based on the up-flow anaerobic sludge blanket process has a capacity of 78 MLD. The second STP, based on the activated sludge process (ASP), has a capacity of 12 MLD.
- Untreated sewage from more than 400[15] locations in Indore city flows into the Khan River. This includes industrial effluents of 2.2 MLD. Downstream from Indore, from Kabitkhedi to Sanwer, water from the Khan River is used for irrigation. This poses a very high risk of food chain contamination.
- Many local sewer lines open into water bodies and into open ground, thereby polluting the environment.

Bhopal

In Bhopal, the entire sewerage network is about 466 km, covering 24 per cent of the city area. However, the Smart City Proposal estimates that the required sewerage network is close to 2,000 km (i.e. about four times the current capacity). In addition to the capacity requirements of the sewerage infrastructure, there are challenges in augmenting treatment capacity and sewage collection efficiency. The total sewage generation is 252 MLD, out of which about 74.53 MLD is treated across seven STPs (Table 6). Therefore, close to 70 per cent of sewage goes untreated. Of the 30 per cent sewage that does get treated, the efficiency of the different technologies is about 80 per cent. One of the drivers of infrastructural inadequacy is the lack of financial resources.

STP location	Year of commissioning	Installed capacity (MLD)	Treatment technology
Badwai	2001	16.7	Oxidation pond
Gondarmau	2001	2.36	Oxidation pond
Maholi Damkheda	2001	25.0	Waste stabilisation pond
Kotra	2001	10.0	Waste stabilisation pond
Ekant Park	2008	8.0	Oxidation pond
Mata Mandir	1959	4.6	Trickling filter
Bawaria Kalan	1975	13.6	Oxidation pond

Table 6
Sewage treatment plants (STPs) in Bhopal

Source: CPCB (2016)[16]

15. ICRIER (2016). Urban Water Systems in India: A Way Forward Available at http://icrier.org/pdf/Working_Paper_323.pdf.Last accessed 16 November 2017
16. CPCB (2016). Environmental Status of Bhopal City. Available at http://cpcb.nic.in/Environment_Status_Report_MadhyaPradesh_Bhopal_2016.pdf. Last accessed 16 November 2017

Sanitation-related challenges due to insufficient and inadequate infrastructure are further compounded by topography and development patterns. Bhopal slopes towards the north and the southeast. Hillocks of different altitudes are situated along the south-western and north-western parts of the city, forming a continuous belt from the Singarcholi up to the Vindhyachal range, to an elevation of 625 m. This has led to dense urban growth in some areas, putting more burdens on those areas. The sloping terrain in Bhopal means that rainwater flows more rapidly towards low-lying areas, creating water-logging and flooding. Further, encroachments have blocked the existing drainage system.

Jabalpur

Management of solid waste and sanitation is an obligatory function of the Jabalpur Municipal Corporation. However, this service is not always performed effectively or efficiently, resulting in problems of SWM. There is a huge baseline service-level gap in every indicator of SWM services by the Jabalpur Municipal Corporation. Households are dependent largely on septic tanks and coal-pit toilets. Jabalpur has many dry latrines. Currently, domestic sludge is disposed directly into open drains meant for storm water discharge. Its septic tanks lead to surface and groundwater pollution. Currently, there is no appropriate or standardised way for the disposal of septic tank sludge. The lack of a sewerage network or underground drainage network makes sewerage management a haphazard process.

Possible risks due to climate change

It is well understood that changes in the temporal and spatial distribution of rainfall due to climate change will result in several climate impacts. Extremes of rain could directly damage sanitation- and water-related infrastructure. This could potentially result in the contamination of ground and surface water. Flooding of pit latrines and septic tanks or structural damage to toilets could pose serious health risks due to contamination. Typically, such impacts are felt across the lower socioeconomic strata of society. Decline in runoff and stagnation of water could provide fertile breeding ground for mosquitoes and other vectors for disease. In periods of drought, water-borne sanitation may potentially be compromised.

Recommendations regarding sanitation from the climate change perspective

Building climate resilience of the sanitation system is important to ensure the proper functioning of a city. As a first step, the city must identify and address gaps in infrastructure. This requires an integrated approach, with participation of local communities,in preparing management plans and identifying adaptation options in the sanitation sector.

The key recommendations for climate-resilient solid waste infrastructure are divided into two categories, i.e.at the planning or policy level and at the implementation level. These are presented in Table 7.

Table 7
Key recommendations for the sanitation sector

Source: Authors' analysis

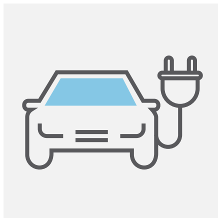
Planning, policy changes, and project development

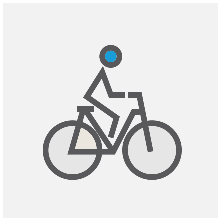
- Adopt an integrated approach for setting up a sewerage and storm-drain network across the city.
- Authorities should identify regular flood hotspots in the city to find the reasons for such flooding.
- Authorities should identify major encroachments over nallahs and drains and remove them at the earliest.
- Strengthen governance and improve water management.
- Improve and share knowledge and information on climate and adaptation measures, and invest in data collection.
- Build long-term resilience through stronger institutions, and invest in infrastructure and in well-functioning ecosystems.

Construction, operation and maintenance, and programme activities

- Clean and unblock drains and nallahs regularly to ensure free flow of rainwater.
- Improve access to sanitation services to strengthen adaptation measures, as they reduce risks of degraded services associated with climatic events (such as discharge of untreated waste during floods).
- Increase financial and technical resources for more frequent and more efficient maintenance and repair of the sewerage system, including STPs, sewerage networks, and pumping stations.
- Enforce design and construction norms for pipelines to protect them from the adverse effects of extreme temperatures.
- Upgrade existing infrastructure to meet future challenges and to cope with the risks associated with climate change.
- Properly design and operate treatment plants that can deliver under extreme-weather conditions.
- Rehabilitate existing sewerage systems and build new systems for the collection and safe disposal of waste water to reduce the risk of regular flash flooding during heavy rains and to prevent groundwater flooding.

3.3 Transport





The planning of transport systems is important both from the perspective of climate-change mitigation as well as adaptation. Planning for low-carbon transport can significantly reduce emissions. Given the longevity of transport infrastructure, investments should be made to ensure climate resilience. Given these objectives, Smart Cities are looking to realign transport systems with area-based development (ABD) plans, to boost the share of public transport, to ensure safety, and to enhance walkability.

Indore

Indore has identified several challenges related to its transport system. First, more than 10 per cent growth in privately owned vehicles has resulted in 60 per cent increase in traffic congestion and deteriorating air quality over the last few years. Second, poor pedestrian and road-user facilities have resulted in road and traffic safety issues. The coverage of footpaths is about 27 per cent, which is far below the required standard of 50 per cent–75 per cent (as per the Ministry of Urban Development). Third, public bus services are provided by Atal Indore City Transport Services Limited. However, these services are inadequate, with only 0.045 buses/1,000 population against the benchmark of 0.4–0.6 buses/1,000 population. Fourth, only 152.6 km out of 355.63 km of the major road network (i.e. less than half) has organised public transport services.

Indore plans to address these issues by strengthening the public transport system through road development, intersection improvements to ensure walkability and safety through the use of street design guidelines (SDG) for Transit-Oriented Development (TOD), no-vehicle zones with smart parking, battery-operated e-rickshaws, real-time monitoring of air quality, and intelligent transport systems (ITS).

ITS will integrate traffic, transit, parking, and payment management using elements of ICT. It will be integrated with the existing and proposed transportation networks/systems (bus rapid transit [BRT], Rail Metro, signals), streamlining traffic and transport management and improving the user experience. ITS will be driven by a central communication network (i.e. the Central Command and Control Centre), with a dashboard for real-time traffic data analysis and information dissemination.

In addition, several ABD proposals have been suggested. These include:

- Draft SDG developed under TOD regulations for improvements and developments in 48.55 km of roads and streets, 47 vehicular intersections, 8 mid-block pedestrian crossings, and pedestrian streets in no-vehicle zones.
- Signalisation and ICT components will be developed through integration with the ITS components of the pan-city proposal.
- Improvement of roads, vehicular intersections, and pedestrian crossings through geometric design as per the SDG. All the roads, streets, and vehicular junctions are to be pedestrian- and non-motorised vehicle (NMV)-friendly for walkability and safety, and will include improved traffic management, trees to shade pedestrian and NMV zones, lateral zoning of streets, and multi-functional zones to accommodate road-user facilities, barrier-free universally accessible pedestrian paths and crossings with a special focus on accessibility for the differently abled. All non-signalised intersections will be designed as table-top junctions with pavement-texture variation to avoid vehicle over-speeding.
- Improvement of traditional market streets through the creation of no-vehicle/pedestrian zones along with the provision of smart parking at walkable distances, and 5 km of no-vehicle streets covering 15.98 per cent area in ABD.
- Provision of 7,200 equivalent car space (ECS) in 12 shared parking facilities in the periphery of no-vehicle zones to meet parking demand.

Bhopal

Bhopal is another city where transport demand is growing rapidly. The high growth rate of vehicular population coupled with limited public transport options has adversely affected the traffic situation. For instance, in the case of public transport, the average waiting time is

20 minutes and the average load factor is 0.92. Without prudent intervention, the situation is likely to get worse in the future.

To address these challenges, Bhopal Smart City Plans have proposed the area based development (ABD) approach. Some of the suggestions are:

- **Pedestrian-friendly pathways**: Shivaji Nagar is planned as a pedestrian-friendly area. Sufficient linkages have been provided within the planned area to connect different parts of Shivaji Nagar. The ground floors of buildings have been planned to promote a high level of activity (business, retail, etc.).
- **Non-motorised transport (e.g. walking and cycling)**: An ABD zone will create a compact and walkable city. The area is within a 5-minute (400m) walk of any transit station (BRT/ Light Rail Transit [LRT]) and within a 10-minute (800m) walk of the LRT station. Shivaji Nagar will be transformed into a green, walkable, and cycle-friendly urban environment.
- **Intelligent traffic management**: ABD will include intelligent traffic management features like dynamic traffic light sequence. It will help reduce congestion on peripheral roads as well as improve road efficiency. The intelligent surveillance system will include automatic number plate recognition and online automatic challans. This will help reduce the need for vigilance by the traffic police and generate traffic discipline among drivers.
- **Non-vehicle streets/zones**: Shivaji Nagar is planned as a vehicle-free zone. Vehicles are restricted to the periphery of the development. Vehicular traffic is allowed in an underground vehicular tunnel to connect different areas. In this way, surface vehicular traffic has been kept out and the ground level is freely available to cyclists and pedestrians.
- **Smart parking**: In the ABD plan, vehicles have been restricted to the periphery of the site, and a peripheral four-lane service road has been designed to provide access to the development on the edge of the site. Multi-storey car parks have been provided to achieve a vehicle-free site.

The average waiting time for public transport in Bhopal is 20 minutes and the average load factor is 0.92

Jabalpur

Jabalpur is being envisaged as a critical link in the logistics value chain due to its central location. It will be set up as a regional logistics centre, with provision of container depots and a container freight station in central India, given its excellent road, rail, and air connectivity. However, achieving this vision requires the improvement of intra-city transport infrastructure. Although major roads are covered by the public transport system, feeder roads have yet to be covered by the same, giving rise to last-mile connectivity issues. Just like Bhopal and Indore, Jabalpur is also moving towards ABD for its transport system. Some of the ABD proposals are:

- Improvement of roads, vehicular intersections, and pedestrian crossings through geometric design as per the SDG.
- Intelligent Traffic Management System consisting of an automatic sensor-based signalling system, real-time traffic data collection and information system, variable message signboard, closed circuit television (CCTV) cameras to monitor traffic flow, automated warning system, and adverse-weather system.

- Development of smart multilevel parking at six locations in the area, providing smart street surface parking for pedestrian areas, real-time data on parking space availability and routes using ICT, reservation of parking slots using Web-based applications,and policy on paid on-street parking.
- Development of smart bus stops at 43 locations.
- Development of a green corridor 2 km in length on Omti Nallah and a pedestrian-friendly civic centre, multi-function zone, mid-block crossings, and mid-block pedestrian refuges on major roads.
- Procurement of 75 battery-operated cycle rickshaws (e-rickshaws) to provide last-mile connectivity on feeder roads.

Possible impacts

Whereas all Smart Cities are planning to overhaul their transport systems, these systems will need to be made climate resilient. Table 8 highlights the possible climate risks across the three MP Smart Cities.

Table 8
Potential climate risks for transport system

Climate risk	Design components likely to be affected
Increasing temperatures	**Pavement and road surface integrity will drive**
	• Draft SDG under TOD • Improvement of roads, vehicular intersections,and pedestrian crossings • Smart parking
	Thermal discomfort will drive
	• Consumer choices about use of non-motorised transport • Design of smart bus stops
	Increased energy and cooling requirements will drive
	• Functioning of ICT components
Increasing precipitation	**Flooding of transportation links will drive**
	• Restricted travel across various modes of transport, including pedestrian-friendly pathways • Access to health facilities, emergency services, food and groceries, etc.

Source: Authors' analysis

Recommendations

Although the majority of actions identified in the Smart City Plans are centred on low- carbon mobility, it is important to make these systems climate resilient. This can be achieved by enabling the resilience of transport infrastructure through policy making and planning. The policy measures could include:

1. Considering future climate parameters at the stage of project planning (in addition to historical data). This will help fine-tune the system capacity to withstand future uncertainty.

2. Modifying technical standards to account for future climate change. This could be done by using pavement materials that are heat resistant; using heat-reflective paints on footpaths; using higher-grade bitumen in road surfaces; specifying capacity standards for drainage infrastructure, etc.

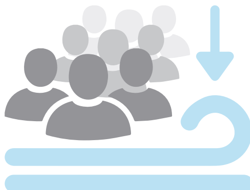
3. Addressing interdependencies during the planning stage. Cities are concentrations or hubs of people, assets, and services that are highly interdependent. The failure of one system (e.g. communications or transport) can significantly impact the functioning of another. Studying interdependencies is critical for prevention and early response in the face of climate-related disasters. For instance, the United Kingdom has developed its first national infrastructure systems model (NISMOD) that models risks and vulnerability to climate change. This helps identify local hotspots and provides decision-making tools to policy makers.

3.4 Flood management

We discuss the existing scenario, potential impacts due to climate change as well as possible solutions for flood management.

Bhopal

The main sources of water for Bhopal are the Upper Lake and the Kolar dam reservoir. The Upper Lake is spread over an area of 6.25 sq km and the supply of water from the lake is about 146 MLD. The lake is mainly rain-fed and the annual average rainfall is 1,260 mm. Supply of raw water from the Kolar dam reservoir is 162 MLD. The dam is located about 40 km from Bhopal city and has a capacity of 265 MCM. Apart from these two sources of surface water, which account for about 90 per cent of the water supply to the city, Bhopal also depends on groundwater sources for 10 per cent of its supplies.



More than 70% increase in Bhopal's population has added immense presssure of its water resources

Bhopal's population has grown from 1.4 million to about 2.4 million, registering an increase of more than 70 per cent in the last decade. The rate of population growth means immense pressure on water resources. Additional requirements of water are proposed to be met from the Narmada River at Hoshangabad, located about 70 km from Bhopal.

The city plans for Bhopal have identified the following shortfalls in water management:

- The increased rate of urbanisation has already created a gap between municipal supply and demand for water. The per capita supply for the city is 108 litres per capita per day (LPCD) (after deducting leakage) while the standard requirement is 135 LPCD.

- Only 49 per cent of the population is covered by the water supply system. There is no 24-hour water supply; water is supplied for only two to three hours in a day.

- There are high losses (~35 per cent) in the transmission and distribution of water.

- The Upper Lake, which is the main source of water supply, has shrunk appreciably from the initial 30 sq km to 8 sq km. These twin lakes also suffer from siltation due to soil erosion in the catchment area. Further, the water level in the lakes is also decreasing and sometimes it is only 2 m below the minimum level of 504 m.

- The city drainage system covers only 30 per cent of the area.

Figure 2
Sources of water for Bhopal city

Source: Anon (2011), 71–City Water–Excreta Survey, 2005–06. Centre for Science and Environment, New Delhi.

Jabalpur

Jabalpur lies at a distance of 15 km from the Narmada River. The water bodies that once led Jabalpur to be known as the city of lakes today have shrunk in size. These 52 water bodies cover an area of 386 hectares. The development plan for Jabalpur envisaged some developments on the reclaimed water bodies. The reclamation levels in these areas are below the high flood level (HFL) and are prone to flooding during heavy rains. The existing drains—Omti Nallah, Moti Nallah, and Urdana Nallah—and the water bodies in the city provide drainage for storm water, but the capacity of these drains and water bodies are already regularly overtopped. In many places, the natural drainage channels are blocked and storm water remains as flood inundation in residential areas. During the rainy season when the intensity of rain is higher or when the waters from the Bargi dam reservoir are released by opening the gates, the backflow from the Omti Nallah and Moti Nallah leads to flooding in the low-lying areas of the city. The areas adjacent to the railway line become waterlogged during heavy rains, with inundation depths of more than 1 m.

The city plans for Jabalpur have identified the following issues with regard to flood management:

- There is no proper storm water drainage system in the city, leading to the flooding of localities every year and resulting in health hazards.
- Jabalpur does not have a sewerage system, and during floods there is potential danger of storm water and sewage getting mixed.
- The construction of the Bargi Dam on the Narmada River has significantly affected the extent of floods in Jabalpur, which occur with greater frequency after the construction of the dam.
- The catchment area of Ukhari Nallah and the areas lying at the foothills of the Madan Mahal Hills were prone to flooding during heavy rains.
- The road from Baldeo Bagh to Damoh Naka remains under flood waters during heavy rains.
- Slums abutting ponds are prone to flooding.

Possible impacts

The major climate risks for Bhopal and Jabalpur are listed below:

Precipitation change	• The Upper Lake is mainly rain-fed and the changes in rainfall patterns will greatly affect the water levels/water availability in the lake. This may affect the city water supply system during drought and more frequent dry periods. The levels in the water reservoirs/lakes would fluctuate on either side of average due to long dry spells between high-intensity rainfall. When the water levels are low, pumps may fail to deliver the required quantities.
	• Urban infrastructure such as road bridges, culverts, and bridges across nallahs/drains would be affected due to high-intensity rainfall, causing flood-like situations, requiring faster and adequate drainage.
	• Slums in low-lying areas and surrounding water bodies would be under threat due to high-intensity rainfall in the basin, resulting in raised water levels in lakes.
	• Due to poor coverage (30 per cent) of the drainage system, the city drainage network is disrupted during high-intensity rainfall.
Temperature change	• Due to changes in temperature, water loss caused by evaporation would be high. Consequently, water levels in the supply reservoirs may fall below the minimum levels, affecting the pumping rates. The water available for use would be less.
	• Change in temperature causes change in soil moisture content, affecting runoff and recharge of lakes and reservoirs.
	• Subsurface flow patterns and groundwater recharge rates would be affected due to changes in soil moisture content due to variations in temperature.
	• The energy requirements for pumping stations would be higher at higher operating temperatures and the failure of the pump mechanism would be more frequent at higher operating temperatures.

Table 9
Possible climate risks for flood management

Source: Authors' analysis

Recommendations for water management from the climate change perspective

After a review of the city plans and existing practices on water management, the following recommendations have been made to build resilience in the water sector:

1. The water management plan for Bhopal city needs to be based on more realistic estimates considering population growth and additional requirements to address climate change impacts. Since the city is planning to draw water from the Narmada river, which is 60–70 km away to meet future demand, pumping and piping adequacy to meet future requirements needs special attention in view of climate change.

2. The changes in the capacity of lakes because of encroachment and drop in water levels due to variations in evaporation and changes in precipitation need a thorough review based on technical studies using hydrological and climate models. The reclamation of water bodies should be avoided as act as water-storage areas and supply sources for cities

and act as an effective flood management mechanism. Although there is no foreseeable threat of riverine flooding given that Jabalpur is located on a plateau, the city's drainage system may not have the necessary capacity for discharging high-intensity rains because the city topography is undulating.

3. The flood management plan for Jabalpur needs to be a comprehensive one, based on a basin-level study. Because of the city's location in the Narmada basin, the catchment area consists of many drains, namely Omti Nallah, Moti Nallah, Shah Nallah, Khandari Nallah, Urdana Nallah, and Ukhari Nallah. Hence, the water bodies in Jabalpur would play a more significant role in flood management compared to other cities.

4. Reclamation of water bodies should be avoided as these bodies act as effective flood management tools and help the city's environment remain climate resilient. Also, the drainage pattern around water bodies always directs the flow into the water body itself, thereby posing a risk to the surrounding area. The silt brought in by these flood/drainage waters settles in the water body, reducing its capacity and size.

5. If any developments in low-lying areas are necessary, they should follow the city drainage plan prepared on the basis of flood inundation levels /HFL as per hydrological/hydraulic studies for the area. The preparation of such plans should take into consideration climate change effects and should also integrate climate-resilience aspects.

6. The city's urban infrastructure such as bridges (road underbridges or RUBs) need to be revamped, retrofitted or redesigned considering flood discharges under climate-change scenarios. Culverts and drainage channels should have additional carrying capacity based on the findings and recommendations of climate studies, as flood discharges under climate-change conditions could increase 50 to 100 per cent over and above the peak discharges predicted occurring under current conditions.

7. The city policy makers should adopt a strategy to implement strict rules to control development to build climate-resilient infrastructure and developments in the city, particularly in low-lying areas and in areas adjoining water bodies, to achieve effective flood management and to augment the storage capacity of the lakes. The disaster management plans should be updated and all stakeholders should agree on these plans in terms of climate resilience and tolerance.

8. *Nallahs* (drains) and water bodies should be de-silted regularly to ensure that they are prepared to discharge flood waters to their full capacity without overflowing.

9. Effective monitoring of the water management system and the related infrastructure, along with the installation of a command control system and an information system on rainfall and flood forecasting and communication, would help in minimising loss and damage in case of a disastrous flood event. Through training, the stakeholders and the public should be made aware of flood management practices and the use of various media for disseminating news about floods and the necessary instructions that should be followed in such events.

4. Climate resilience framework and roadmap

Image: iStock

This section introduces the context for and presents a climate-resilience framework and a roadmap for the MP Smart Cities.

Global temperatures are climbing. The increase so far is already unleashing acute-weather events. Building resilience is essential. In the next 10 to 20 years, 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.

City authorities and infrastructure owners, operators, and investors need to integrate climate-change considerations into their strategic plans to protect against acute-weather events that are already occurring and to prepare for the additional impact of chronic events in the future.

Two outputs of this FCO-funded project are a climate-resilience framework for Indian cities and a roadmap for the implementation of this framework. These are set out in sections 5.2 to 5.8, following an introduction on why MP Smart Cities should invest in climate resilience.

4.1 Why should the MP Smart Cities invest in climate resilience?

Based on the Climate Change Risk Profile for Jabalpur, Bhopal and Indore MP Smart City studies (Section 2 and Annexures A–E), the following projected changes in future temperature and rainfall, and the subsequent impacts on a selection of priority sectors (more details can be found in Chapter 4) expected, are summarised in Table 10.

Table 10
Summary of expected future climate change and impacts on key infrastructure sectors

Source: Authors' compilation

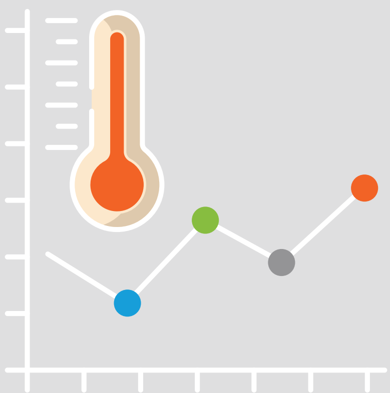
Temperature-related changes expected: **Warmer conditions, including more intense and more frequent high-temperature extremes**	**Temperature-related impacts expected:** **Leading to more prolonged hot periods and heatwaves, affecting infrastructure integrity**
Increasing mean temperatures Increasing number of warmer days Increasing number of warmer nights 	**Transport infrastructure:** heat damage to component materials and to signalisation/ICT/Intelligent Traffic Management system equipment, surface cracking, expansion of bridge joints. Reduced willingness of people to use non-motorised transport. **Water supply infrastructure:** low flow, increased evaporation, fall in water quality, increased risk of water shortage. **Solid waste management:** increased fire risk, increased vermin and odour at landfills and waste facilities. Higher rates of decomposition, increase in number of insects spreading disease. Overheating and reduced service of collection vehicles. **Water and flood management:** altered evapotranspiration and soil moisture levels, increased variability in runoff and discharge. Increased energy demand made on current pumping stations.

Table 10 contd...

Rainfall-related changes expected: **Higher annual rainfall totals and more frequent and heavy rainfall events**	Rainfall-related impacts expected: **Leading to both more prolonged wet periods and more prolonged dry periods, affecting infrastructure integrity**
Higher total rainfall	**Transport infrastructure:** overloading of drainage system, flood and storms damage to transport routes and supporting equipment.
More frequent heavy-rainfall days	**Water supply infrastructure:** increased risk of damage caused by flood/flash flood, as infrastructure and storage facilities are unable to accommodate excess water, overwhelming sewer capacity.
More consecutive dry days	**Solid waste management:** increase in waste in post-flood events, disruption in access to waste disposal facilities, disruption in waste collection. Flooding of landfills and waste facilities, leading to disruption of processing and resulting in water contamination.
	**Sanitation:** damage to basic sanitation facilities and further reduced access to basic sanitation for low-income settlements; inundation and water stagnation,resulting in the spread of waste, germs, odours, and disease; contamination of river water during and after flood events.
	Water and flood management: increased risk of damage caused by flood/flash flood and inundation.

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

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

4.2 Overview of framework

Based on international good practice in undertaking climate assessment and resilience planning, the following high-level framework (Figure 5-1) 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 integrate climate resilience into city planning, design, and operation, as well as into policies and programmes. The framework has been tailored to local contexts of Indian cities where possible, and the key tasks under each step can be refined further.

The resilience framework helps Indian city authorities understand the impacts that a changing climate could have on their city and how to plan and monitor the actions they need to take to mitigate risks and cope with these challenges.

Figure 3
Overview of climate resilience framework for Indian cities

Source: Authors' compilation

Further details for each step set out in the resilience framework are given below. This framework describes high-level steps and tasks to aid Indian cities in planning and taking actions to increase climate resilience. Based on the work carried out under this project, the earlier steps are being implemented and progress in this regard is highlighted where relevant for the three MP Smart Cities. Further work as a follow-on to this project is needed to move the framework forward and to provide more tailored guidance and practical advice on how to undertake the key tasks.

Step 1. Understanding

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

1. Understanding **What is climate resilience? How does it affect my city?**			**Progress check**
Step	**Purpose**	**Key tasks**	**Details and status**
1.1	Understand what climate change and climate resilience are and why it is important for the city to prepare to tackle them	Raise awareness among city officials and technical sector / department staff. Hold interactive training sessions for senior city officials and sector / department staff.	Initial discussions on climate resilience held with FCO and MP Smart City officials in October 2016. *Status: Started, further work needed*
1.2	Define context and baseline, and collate relevant data	Collect available data on the larger context relevant to the city and the wider region, and review data quality and identify any gaps in data. 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. *Status: Started, further work needed*
1.3	Agree on nature and extent of support and resources required	Get senior-level support for conducting the climate resilience assessment. Form a team (with a minimum of two people) to undertake the general climate resilience assessment.	Senior-level commitment to participate in the FCO project given. Further commitment is needed to continue and form a working group or team for a more detailed assessment across more sectors. *Status: Further commitment needed*
1.4	Stakeholder engagement, communication, and transparency	Identify and engage with all relevant stakeholders.	*Status: Not started*

Step 2. Scoping

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

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

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 **What are the key climate-resilience risks faced by the city?**			**Progress check**
Step	**Purpose**	**Key tasks**	**Details and status**
3.1	Assessment of climate likely to be faced by cities in the future	Identify trend of various climate variables (e.g. average temperature, heat days, intensive-rainfall events), based on one or ideally on a range of different climate scenarios, their implications and limitations. Identify range of percentage changes for relevant climate variables.	Latest climate projections and assessment based on Global Climate Models completed. *Status: Completed from information drawn from available sources, more regional and local modelling could be considered*
3.2	Assessment of climate risks facing the city services	List expected (direct and indirect) impacts (threats, opportunities) 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. Indicate impacts of timescales (short/medium/longer term) Indicate level of confidence (high/medium/low) in dealing with such impacts.	Initial analysis completed for three sectors under FCO project. More detailed assessment needed. *Status: Started*
3.3	Define acceptable level of risk	Define level of risk that the city is prepared to face or for which it is prepared to build resilience against. Define the minimum amount of disruption that the city is preparing to face during an extreme event.	*Status: Not started*
3.4	Understand what climate change and climate resilience are and why it is important for the city to prepare to tackle them	Raise awareness among city officials and technical sector / department staff. Hold interactive training sessions for senior city officials and sector / department staff.	Initial discussions on climate resilience held with FCO and MP Smart City officials in October 2016. *Status: Started, further work needed*

Step 4: Decision-making and resilience planning

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

4. Decision-making and resilience planning **What are the climate-resilience strategies and plans that deliver the optimum value for the city?**			**Progress check**
Step	**Purpose**	**Key tasks**	**Details and status**
4.1	Identification of 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. Assess potential costs and benefits and other supportive processes that may be needed to ensure implementation.	The FCO project has suggested that initial resilience measures should be considered in the selection of sectors. *Status: Started, further work needed*
4.2	Climate-resilience and climate-induced disaster risk planning	Select and prioritise resilience measures in consultation with relevant stakeholders. Develop draft resilience plan to gather all activities and to provide strategic direction.	The FCO project has suggested that a roadmap should be given to facilitate the start of the development of the plan. *Status: Started, further work needed*
4.3	Integration of climate change adaptation and resilience into decision-making process	Identify major ways to support implementation of measure by making changes to existing or upcoming city policies, planning requirements, and supplier and contractual requirements.	FCO project sets out ways to support implementation as suggested in overarching roadmap. *Status: Started, further work needed*

Step 5: Implementation and monitoring

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

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

4.3 Overarching climate resilience roadmap

An overarching climate resilience roadmap covering priority actions in the short, medium, and longer terms is given in Figure 4, setting out the immediate and next steps for integrating the climate resilience framework into city planning and policy making for the MP Smart Cities.

Sector-specific roadmaps, with details of resilience-related recommendations over the short to longer terms, are given in the sectoral analysis in Chapter 4 of this report.

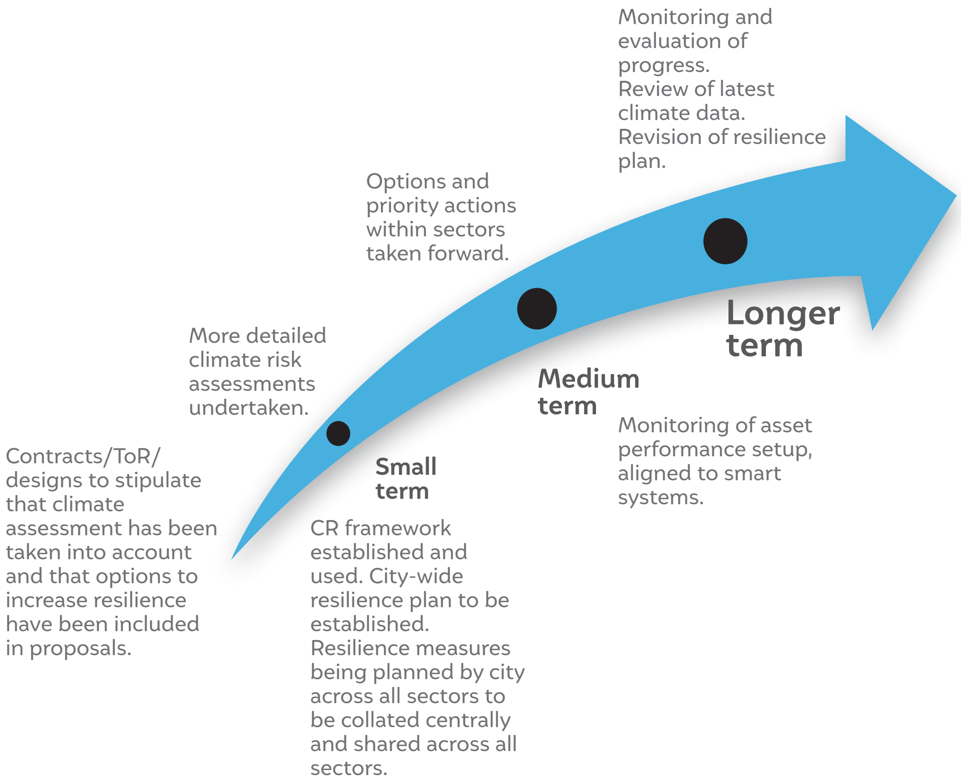


Figure 4
Overarching climate resilience roadmap
Source: Authors' compilation

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

To make immediate progress, it is recommended that a section on the need to undertake a climate screening assessment should be included, as well as a section on appropriate designs and options to increase resilience of (and under) any proposed plans, designs, and developments by the city and its contractors. Below is an example of such a draft text that could be tailored and used by the MP Smart Cities immediately and included as standard text in the relevant Terms of Reference to ensure that climate resilience is considered as early as possible in the development and planning of the city.

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

High-level screening to identify priority risk areas for more detailed assessment

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

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:

- Identification of the current climate risks in the city and in the immediate surrounding areas,
- Regional climate change and risk context;
- Potential direct impacts on infrastructure systems, assets, and planned developments;
- Potential indirect impacts such as climate-driven changes in land use patterns and water demand;
- Potential interdependencies between critical infrastructure links, nodes, and hubs, and their supporting infrastructure.

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

- Extreme flood events (which might affect probable maximum flood [PMF])
- Extreme high-temperature and dry events (which could lead to heat-wave and drought conditions, affecting the integrity of infrastructure and its operation)

On completion of the high-level screening, relevant climate model data for the region should also be collected in preparation for the detailed Climate-risk assessment. The assessment should cover the full range[17] of future climate change that can be expected using information from Global Climate Models [GCMs as well as Regional Climate Model].

The **City Climate Risk Profile** provides an initial compilation of climate projections and observed changes relevant for the city, with projected temperature and rainfall changes based on the current Intergovernmental Panel on Climate Change Fifth Assessment Report GCMs, alongside key messages on and implications for climate change risk assessment of the city. This City Climate Risk Profile is included as an annexure to this Terms of Reference, and it should be used as the starting reference point for 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 through the high-level screening stage, and should be undertaken with the agreement of the city authorities. It should consist of a literature review, data analysis, and risk modelling for a range of scenarios, covering 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 risks identified as priority or significant risks. Specialists in the associated risk topics should be involved at this stage to assess any changes to the risk profile and to recommend the most effect ways of managing the identified risks.

A risk management plan is intended to ensure that any design options not currently resilient under the envisaged climate scenarios can be addressed appropriately.

17. The requirement here is to include the full range of RCP emissions scenarios (i.e. 2.6–8.5) and the envelope of results from the full set of CMIP 5 model integrations, as described in IPCC WG1 AR5 Annex 1 [Available at www.ipcc.ch/ar5/wg1/].

Appendix A. Bhopal climate risk profile

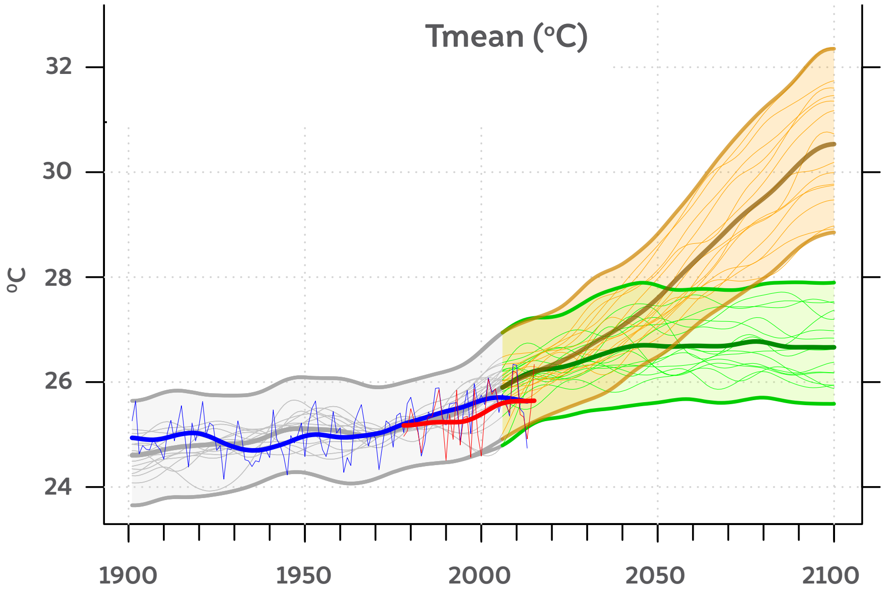


Figure A1
Increases in mean temperature for Bhopal

Source: Authors' analysis

Obs station
Obs gridded
Historic
RCP2.6
RCP8.5

Both observations and simulations show an upward trend in mean annual temperature. Under a high emissions scenario, this trend is projected to continue until the end of the century, with a rise of 4.3°C on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 1.2°C on average.

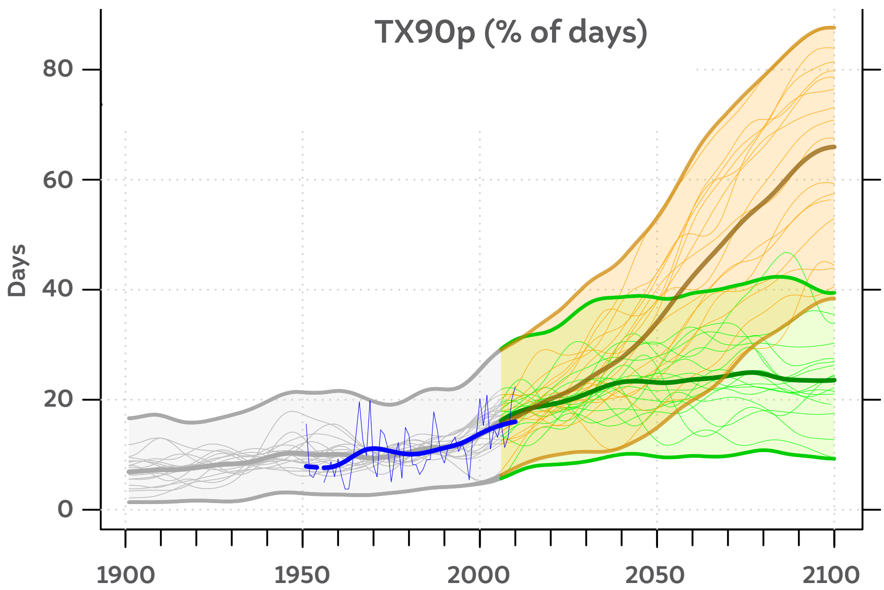


Figure A2
Increases in temperature extremes for Bhopal

Source: Authors' analysis

Obs gridded
Historic
RCP2.6
RCP8.5

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 50 days on average from 1981-2010 to 2071-2100 under a high emissions scenario (and the number of heat wave days to increase by around 170 days on average). If emissions decrease rapidly, the rise in warm days is limited to about 10 days on average (and the rise in heat wave days is about 30 days on average).

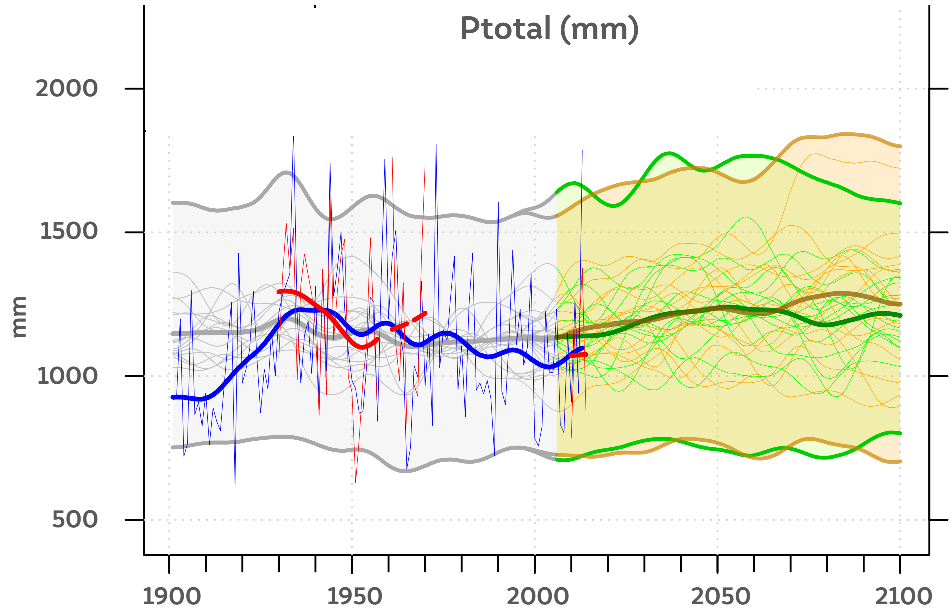


Figure A3
Increases in mean precipitation for Bhopal

Source: Authors' analysis

Obs station
Obs gridded
Historic
RCP2.6
RCP8.5

The observations are dominated by large decade-to-decade and year-to-year variability. The simulations show a general tendency towards increasing total annual rainfall, although variability is large. Under a high emissions scenario, total annual rainfall is projected to increase by about 13 per cent (about 145mm) on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 70mm.

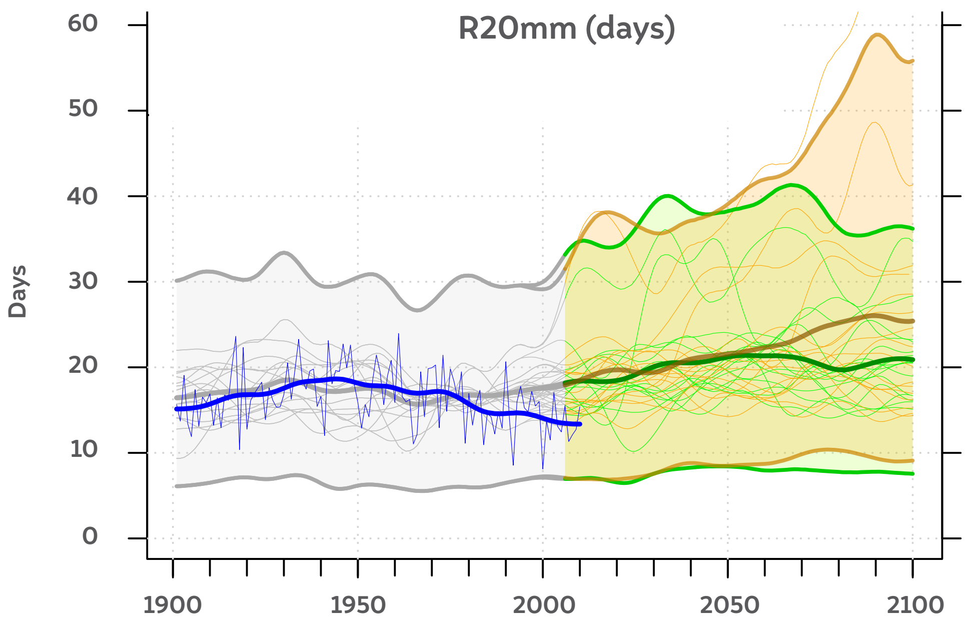
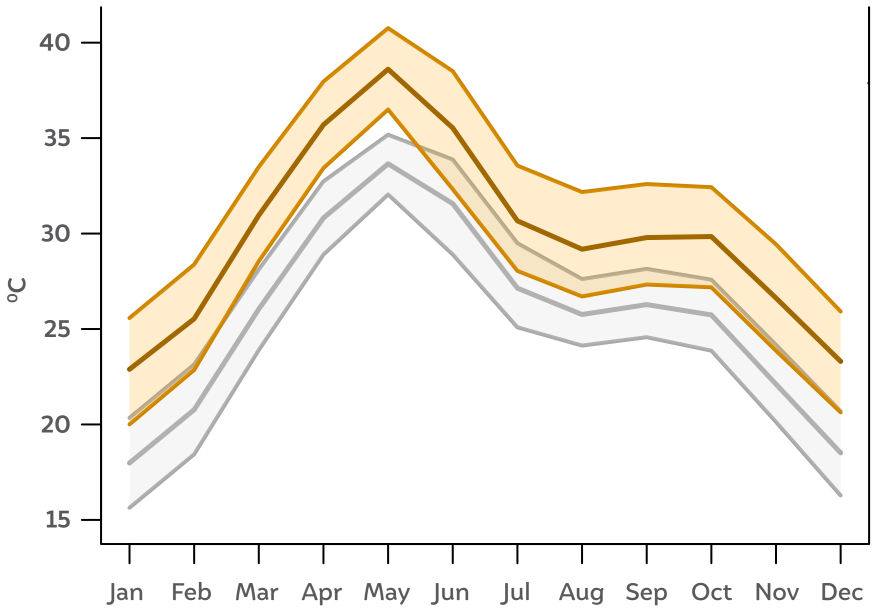


Figure A4
Number of heavy-rainfall days for Bhopal

Source: Authors' analysis

Obs gridded
Historic
RCP2.6
RCP8.5

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 20mm (shown here), for example, is projected to increase by about 8 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 (perhaps even a slight increase with high emissions) from an average of about 100 days, with continuing large year-to-year variability.



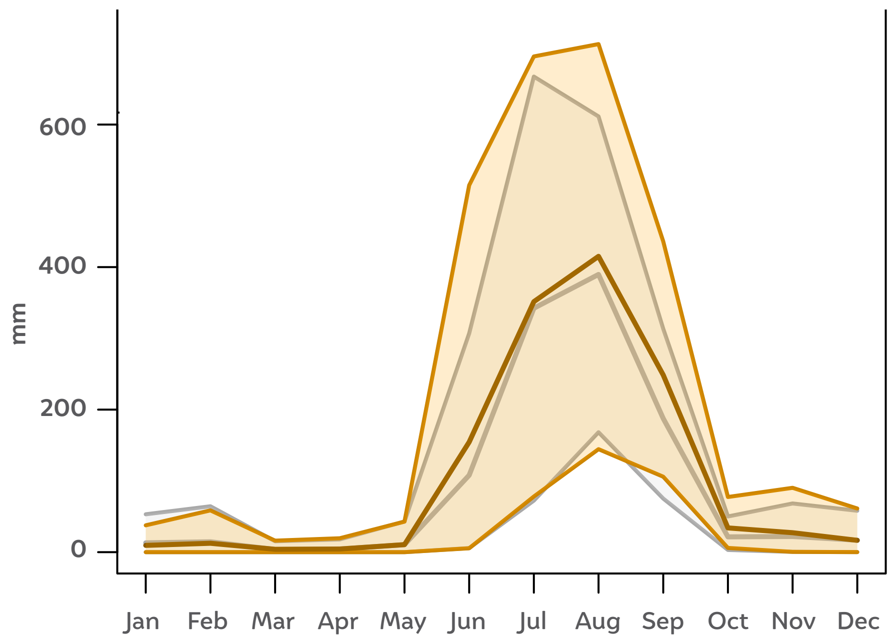


Figure A5
Simulated seasonal cycles of monthly temperature (top) and rainfall (bottom)

Source: Authors' analysis

1981-2010
2071-2100

These figures show the simulated seasonal cycles of mean monthly temperature (left) and total monthly rainfall (right) for 1981-2010 (grey) and 2071-2100 for the high RCP8.5 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 rainfall (August).

	Observed 1981-2010	2030s - RCP8.5	2050s - RCP8.5	2080s - RCP8.5	2080s - RCP2.6
Temperature					
Mean temperature	25°C	+1.4 (0.9 to 1.7) °C	+2.1 (1.5 to 2.7) °C	+4.3 (3.0 to 5.4) °C	+1.2 (0.5 to 1.8) °C
Warm days	13 days	+13 (7 to 20) days	+21 (9 to 32) days	+47 (27 to 64) days	+11 (4 to 23) days
Warm nights	13 days	+21 (14 to 28) days	+33 (24 to 46) days	+62 (51 to 75) days	+16 (6 to 27) days
Rainfall					
Total rainfall	1,048 mm	+7 (-4 to +17)%	+8 (-7 to +18)%	+13 (-8 to +29)%	+6 (-6 to +19)%
Heavy-rainfall days	14 days	+3 (-1 to +9) days	+4 (-1 to +14) days	+8 (0 to +27) days	+3 (-1 to +10) days
Consecutive dry days	98 days	+3 (-11 to +21) days	+4 (-14 to +23) days	+5 (-17 to +29) days	0 (-13 to +9) days

Table A1
Observed and projected changes for temperature and rainfall for Bhopal

Source: Authors' analysis

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 for Bhopal

- The Bhopal climate is subject to large year-to-year variability particularly for rainfall. Thus even in the absence of anthropogenic climate change, this Smart City needs to be resilient to this natural variability.
- Observed records for the Bhopal region show emerging trends in temperature over the last few decades – in particular a clear trend towards higher temperatures and more frequent high temperature extremes.
- Climate projections show a strengthening of the observed temperature trends, particularly with higher greenhouse emissions, as well as a tendency towards somewhat higher rainfall totals and more intense and frequent rainfall extremes.
- If global warming can be constrained to 2°C or less with respect to preindustrial conditions, the impacts of climate change would be substantially reduced for Bhopal, particularly in the second half of the century.

Table A2
Climate change and potential risks

Source: Authors' analysis

Projected climate changes	Potential impacts and risks
Warmer conditions, including more intense and 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. • Negative impacts and constraints on labour productivity, particularly on outdoor workers. • 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. • Possible implications for water balance and the quantity and quality of water resources (also taking into consideration the likely persistence of long dry spells and increased evaporation with warmer conditions).

Appendix B. Gwalior climate risk profile

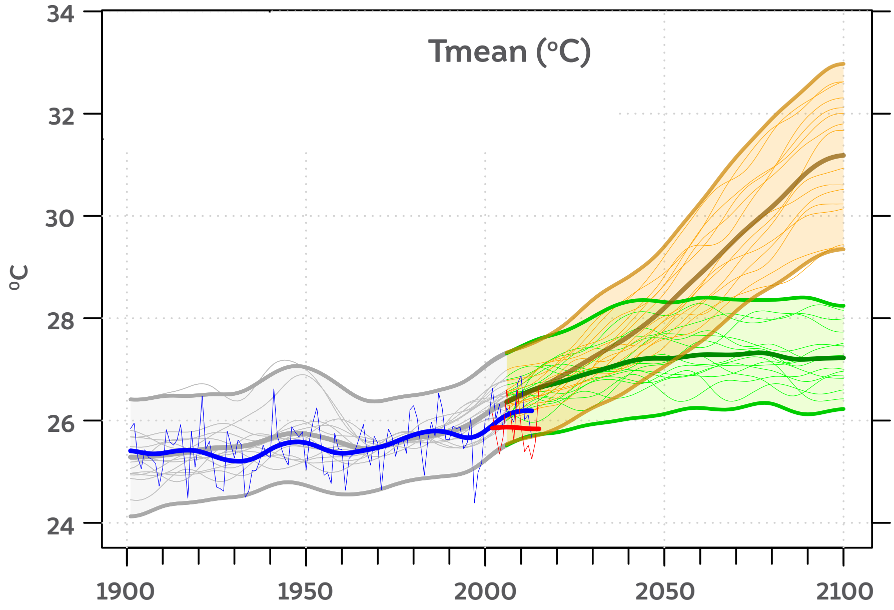


Figure A1
Increases in mean temperature for Gwalior

Source: Authors' analysis

Obs station
Obs gridded
Historic
RCP2.6
RCP8.5

Both observations and simulations show an upward trend in mean annual temperature. Under a high emissions scenario, this trend is projected to continue until the end of the century, with a rise of 4.6°C on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 1.3°C on average.

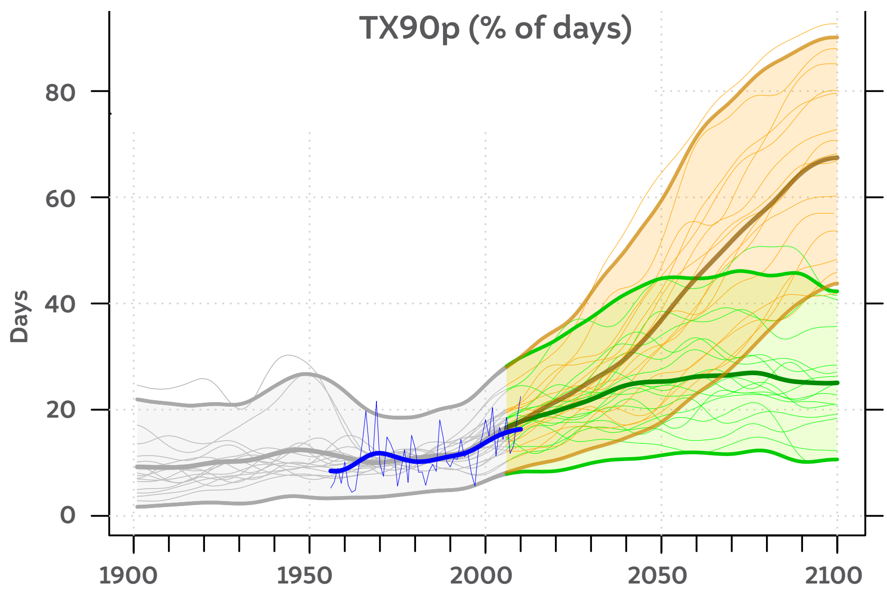


Figure B2
Increases in temperature extremes for Gwalior

Source: Authors' analysis

Obs gridded
Historic
RCP2.6
RCP8.5

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 50 days on average from 1981-2010 to 2071-2100 under a high emissions scenario (and the number of heat wave days to increase by around 175 days on average). If emissions decrease rapidly, the rise in warm days is limited to about 15 days on average (and the rise in heat wave days is about 35 days on average).

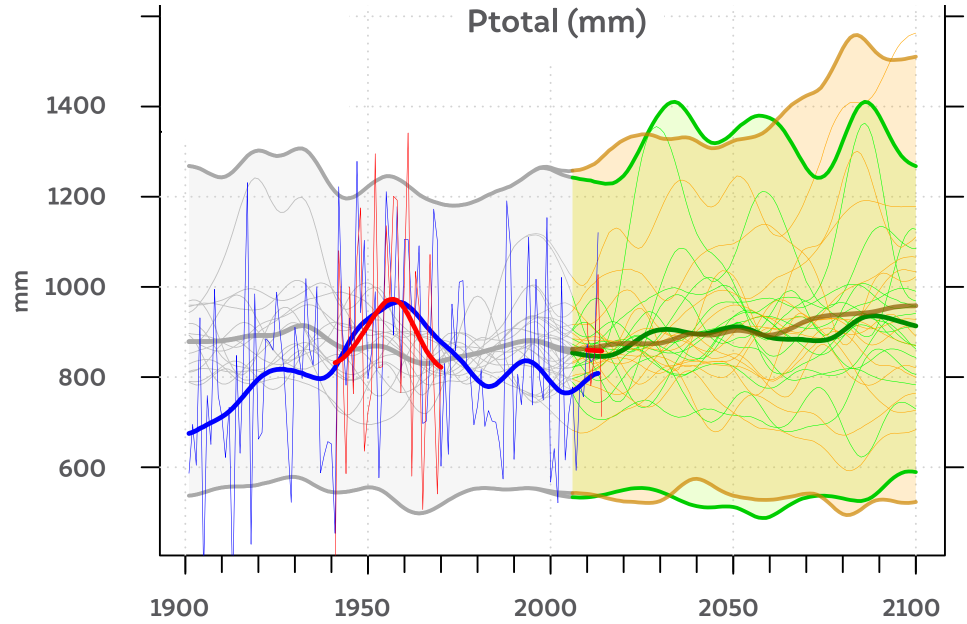


Figure B3
Increases in mean precipitation for Gwalior

Source: Authors' analysis

Obs station
Obs gridded
Historic
RCP2.6
RCP8.5

The observations are dominated by large decade-to-decade and year-to-year variability. The simulations show a slight tendency towards increasing total annual rainfall, although variability is large. Under a high emissions scenario, total annual rainfall is projected to increase by about 9 per cent (about 80mm) on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 40mm.

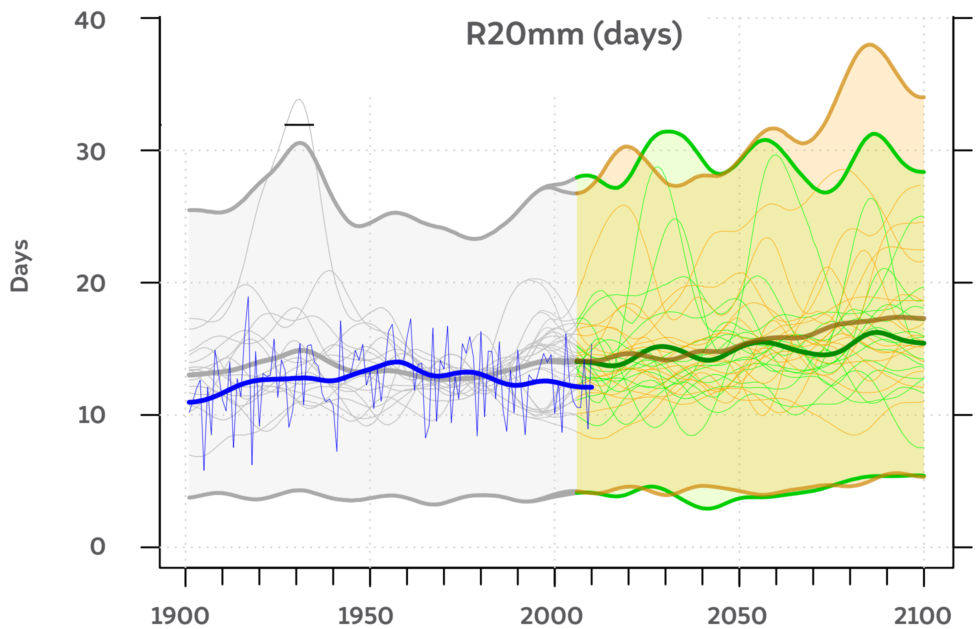


Figure B4
Number of heavy-rainfall days for Gwalior

Source: Authors' analysis

Obs gridded
Historic
RCP2.6
RCP8.5

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 general tendency towards more frequent heavy rainfall events. The number of days per year with rainfall greater than 20mm (shown here), for example, is projected to increase by about 3 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 (perhaps even a slight increase with high emissions) from an average of about 100 days, with continuing large year-to-year variability.

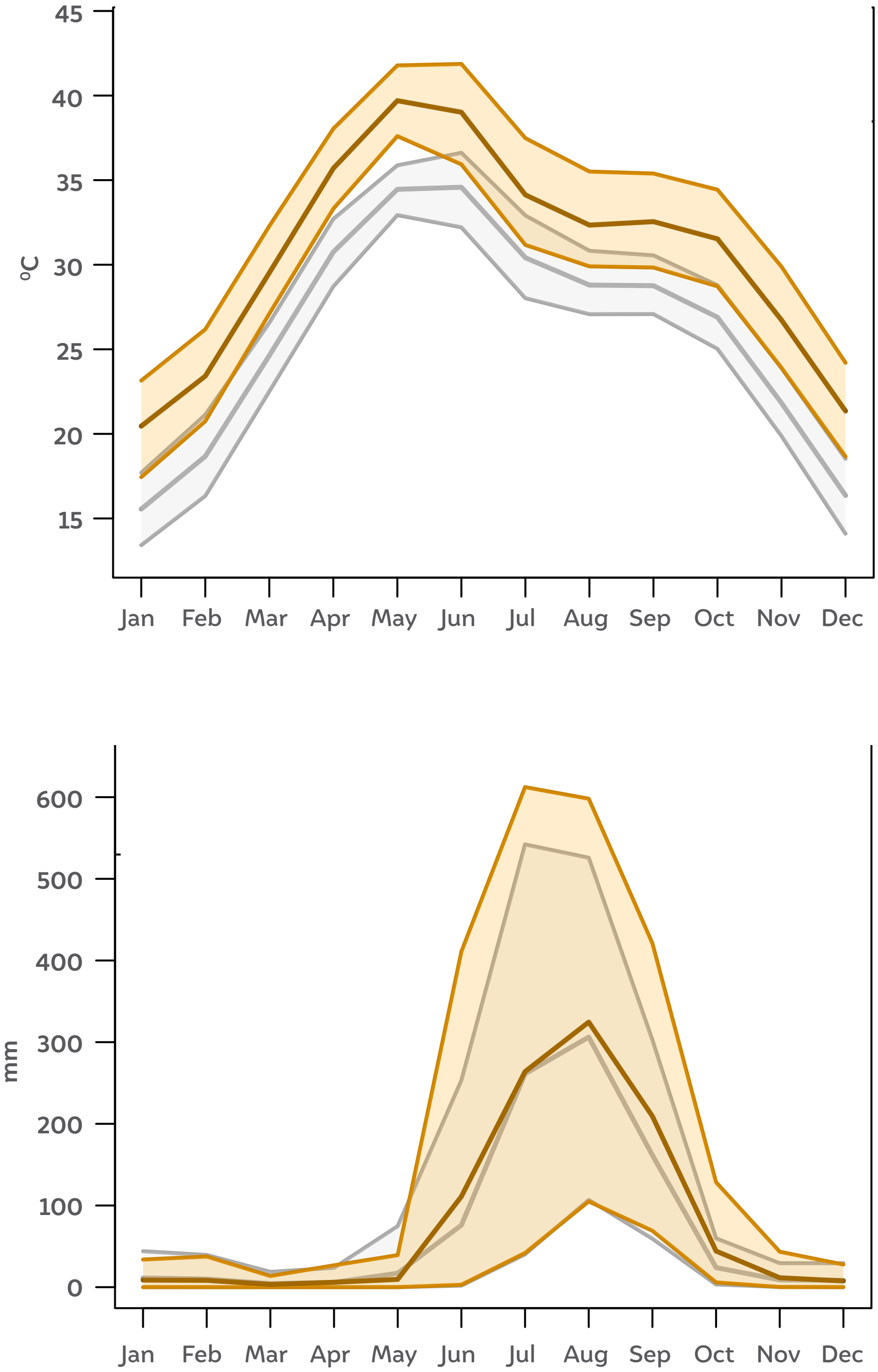


Figure B5
Simulated seasonal cycles of monthly temperature (top) and rainfall (bottom)

Source: Authors' analysis

1981-2010
2071-2100

These figures show the simulated seasonal cycles of mean monthly temperature (left) and total monthly rainfall (right) for 1981-2010 (grey) and 2071-2100 for the high RCP8.5 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 rainfall (August).

	Observed 1981-2010	2030s - RCP8.5	2050s - RCP8.5	2080s - RCP8.5	2080s - RCP2.6
Temperature					
Mean temperature	25.9°C	+1.5 (1.0 to 1.8) °C	+2.2 (1.6 to 2.8) °C	+4.6 (3.2 to 5.6) °C	+1.3 (0.7 to 1.9) °C
Warm days	13 days	+15 (7 to 24) days	+23 (11 to 40) days	+49 (29 to 68) days	+13 (5 to 27) days
Warm nights	14 days	+20 (14 to 24) days	+30 (23 to 38) days	+60 (49 to 71) days	+15 (8 to 24) days
Rainfall					
Total rainfall	787 mm	+2 (-14 to +12)%	+3 (-15 to +15)%	+9 (-21 to +37)%	+5 (-10 to +16)%
Heavy-rainfall days	12 days	+1 (-3 to +3) days	+2 (-2 to +7) days	+3 (-3 to +9) days	+2 (-2 to +6) days
Consecutive dry days	90 days	+2 (-7 to +16) days	+2 (-10 to +21) days	+7 (-18 to +28) days	0 (-12 to +9) days

Table B1
Observed and projected changes for temperature and rainfall for Gwalior

Source: Authors' analysis

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 for Gwalior

- The Gwalior climate is subject to large year-to-year variability particularly for rainfall. Thus even in the absence of anthropogenic climate change, this Smart City needs to be resilient to this natural variability.

- Observed records for the Gwalior region show emerging trends in temperature over the last few decades – in particular a clear trend towards higher temperatures and more frequent high temperature extremes.

- Climate projections show a strengthening of the observed temperature trends, particularly with higher greenhouse emissions, as well as a slight tendency towards somewhat higher rainfall totals and a general tendency towards more intense and frequent rainfall extremes.
- If global warming can be constrained to 2°C or less with respect to preindustrial conditions, the impacts of climate change would be substantially reduced for Gwalior, particularly in the second half of the century.

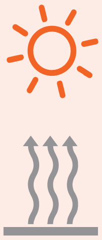
Projected climate changes		Potential impacts and risks
Warmer conditions, including more intense and frequent high temperature extremes and heat wave days		• Human heat stress and other negative health effects including potential increases in mortality, particularly if air quality also decreases. • Negative impacts and constraints on labour productivity, particularly on outdoor workers. • 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. • Possible implications for water balance and the quantity and quality of water resources (also taking into consideration the likely persistence of long dry spells and increased evaporation with warmer conditions).

Table B2
Climate change and potential risks

Source: Authors' analysis

Appendix C. Indore climate risk profile

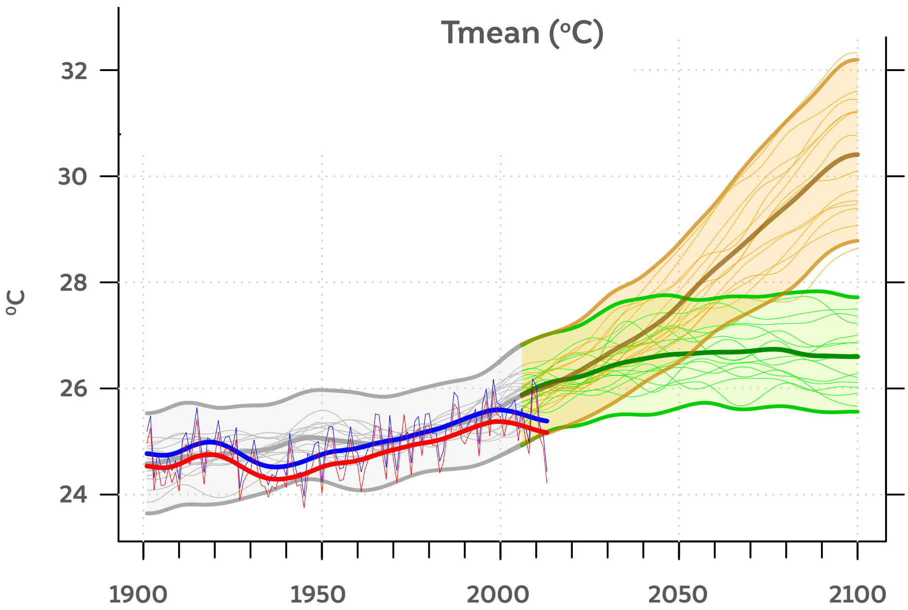


Figure A1
Increases in mean temperature for Indore

Source: Authors' analysis

Both observations and simulations show an upward trend in mean annual temperature. Under a high emissions scenario, this trend is projected to continue until the end of the century, with a rise of 4.3°C on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 1.1°C on average.

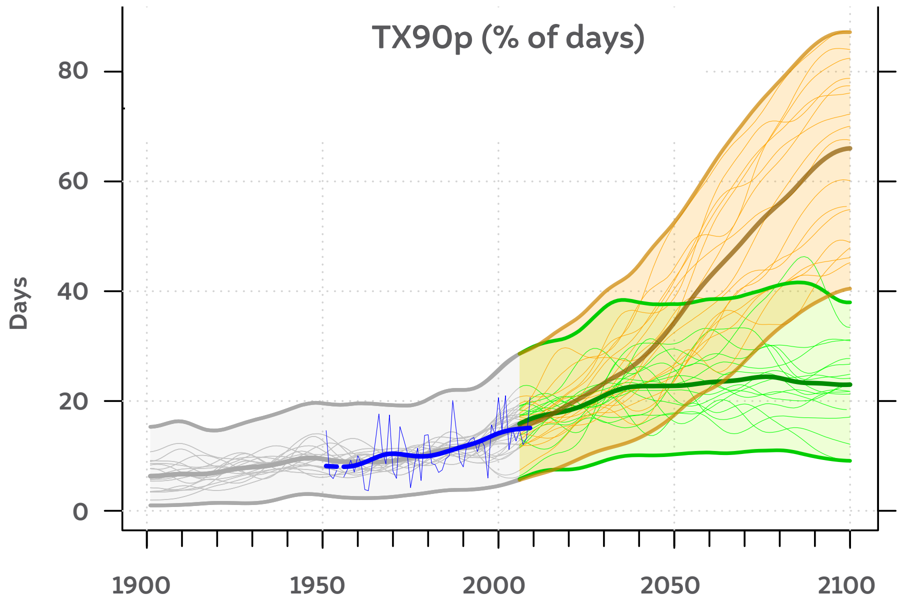


Figure C2
Increases in temperature extremes for Indore

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 50 days on average from 1981-2010 to 2071-2100 under a high emissions scenario (and the number of heat wave days to increase by around 170 days on average). If emissions decrease rapidly, the rise in warm days is limited to about 10 days on average (and the rise in heat wave days is about 30 days on average).

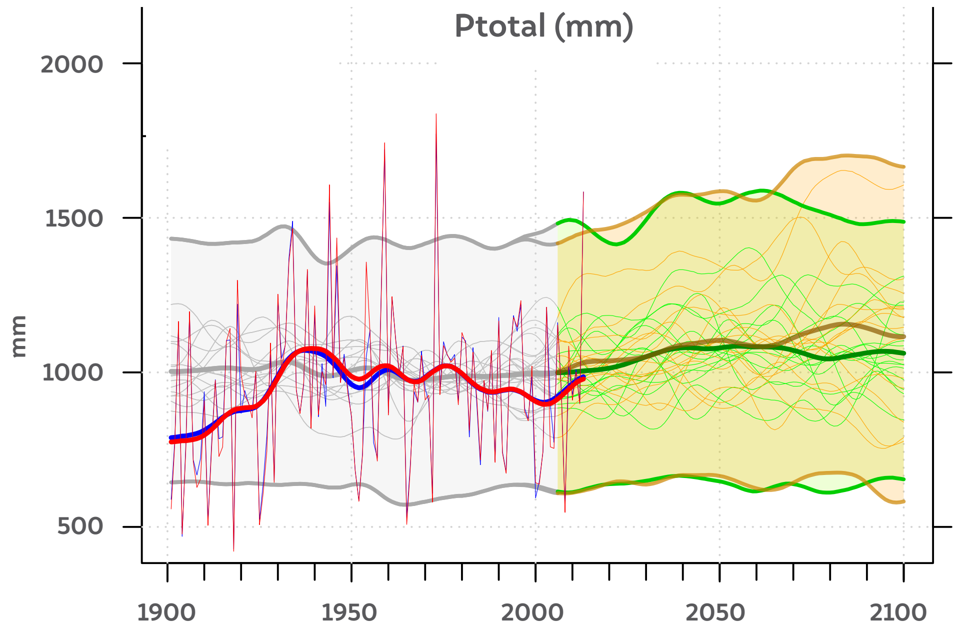


Figure C3
Increases in mean precipitation for Indore

Source: Authors' analysis

Obs station
Obs gridded
Historic
RCP2.6
RCP8.5

The observations are dominated by large decade-to-decade and year-to-year variability. The simulations show a general tendency towards increasing total annual rainfall, although variability is large. Under a high emissions scenario, total annual rainfall is projected to increase by about 15 per cent (about 150mm) on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 70mm on average.

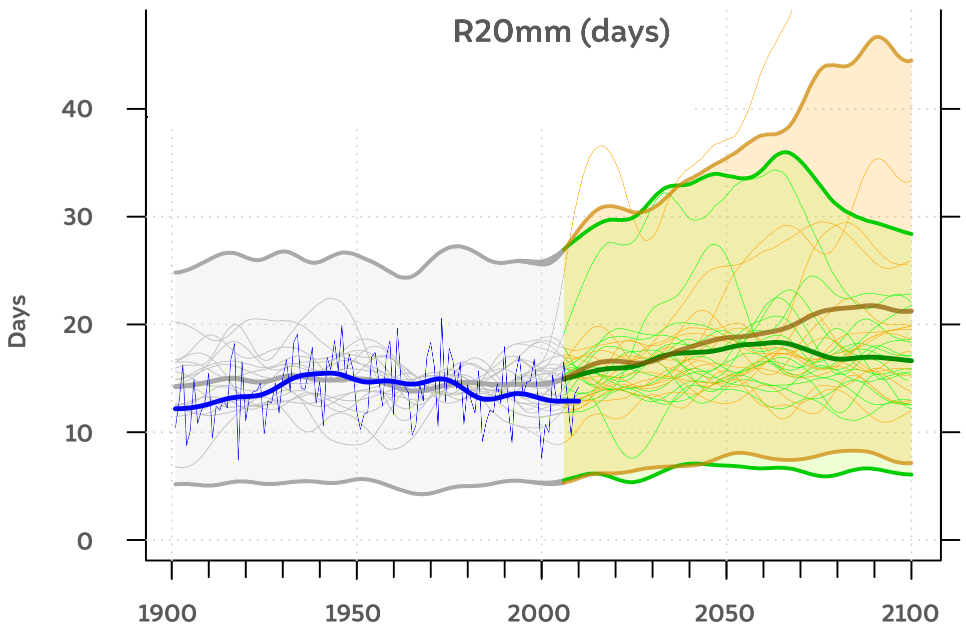
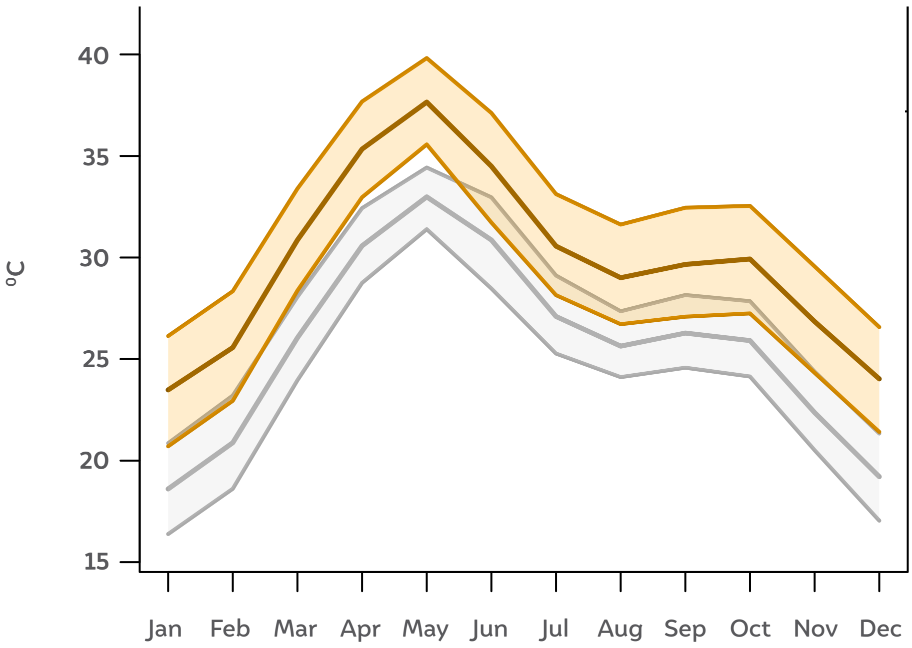


Figure C4
Number of heavy-rainfall days for Indore

Source: Authors' analysis

Obs gridded
Historic
RCP2.6
RCP8.5

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 20mm (shown here), for example, is projected to increase by about 7 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 (even a slight increase with high emissions) from an average of about 125 days, with continuing large year-to-year variability.



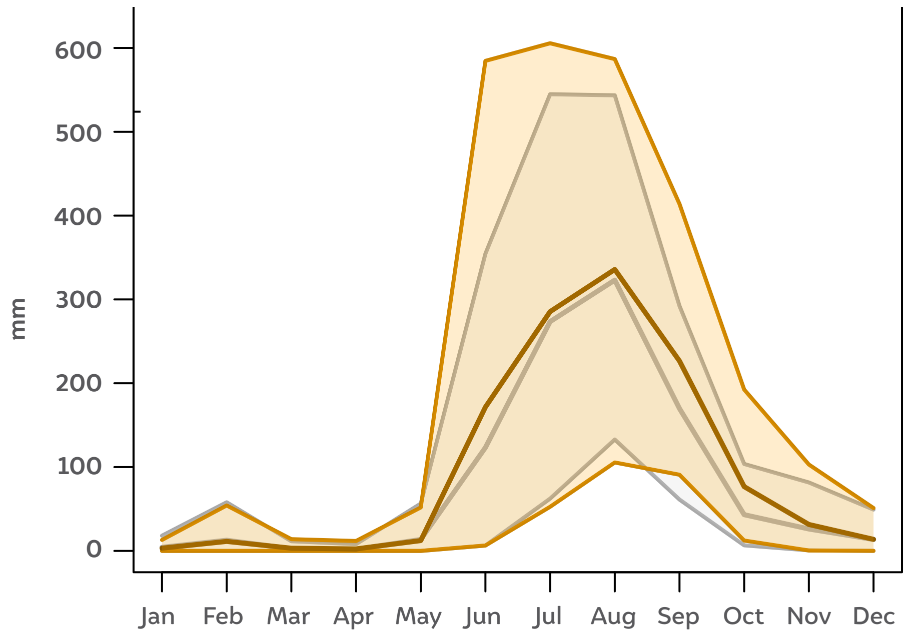


Figure C5
Simulated seasonal cycles of monthly temperature (top) and rainfall (bottom)

Source: Authors' analysis

1981-2010
2071-2100

These figures show the simulated seasonal cycles of mean monthly temperature (left) and total monthly rainfall (right) for 1981-2010 (grey) and 2071-2100 for the high RCP8.5 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 rainfall (August).

Table C1
Observed and projected changes for temperature and rainfall for Indore

Source: Authors' analysis

	Observed 1981-2010	2030s - RCP8.5	2050s - RCP8.5	2080s - RCP8.5	2080s - RCP2.6
Temperature					
Mean temperature	25°C	+1.3 (0.9 to 1.7) °C	+2.1 (1.5 to 2.6) °C	+4.3 (3.0 to 5.4) °C	+1.1 (0.4 to 1.8) °C
Warm days	13 days	+12 (7 to 19) days	+21 (12 to 32) days	+47 (29 to 64) days	+10 (3 to 20) days
Warm nights	13 days	+21 (13 to 30) days	+34 (23 to 45) days	+63 (52 to 76) days	+17 (6 to 28) days
Rainfall					
Total rainfall	787 mm	+8 (-3 to +21)%	+10 (-3 to +22)%	+15 (-12 to +37)%	+7 (-7 to +21)%
Heavy-rainfall days	12 days	+3 (0 to + 9) days	+4 (+1 to +13) days	+7 (-1 to +23) days	+3 (-1 to +8) days
Consecutive dry days	90 days	+4 (-15 to +24) days	+5 (-19 to +28) days	+6 (-16 to +37) days	-1 (-17 to +15) 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 almost always 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 for Indore

- The Indore climate is subject to large year-to-year variability particularly for rainfall. Thus even in the absence of anthropogenic climate change, this Smart City needs to be resilient to this natural variability.
- Observed records for the Indore region show emerging trends in temperature over the last few decades – in particular a clear trend towards higher temperatures and more frequent high temperature extremes.

- Climate projections show a strengthening of the observed temperature trends, particularly with higher greenhouse emissions, as well as a tendency towards more intense and frequent rainfall extremes.
- If global warming can be constrained to 2°C or less with respect to preindustrial conditions, the impacts of climate change would be substantially reduced for Indore, particularly in the second half of the century.

Table C2
Climate change and potential risks

Source: Authors' analysis

Projected climate changes	Potential impacts and risks
Warmer conditions, including more intense and 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. • Negative impacts and constraints on labour productivity, particularly on outdoor workers. • 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. • Possible implications for water balance and the quantity and quality of water resources (also taking into consideration the likely persistence of long dry spells and increased evaporation with warmer conditions.

Appendix D. Jabalpur climate risk profile

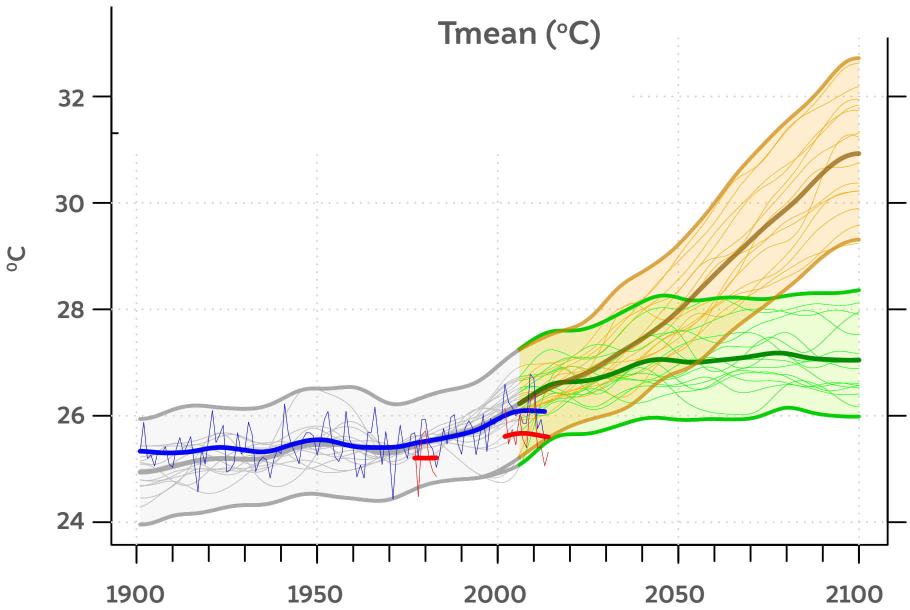


Figure D1
Increases in mean temperature for Jabalpur

Source: Authors' analysis

Obs station
Obs gridded
Historic
RCP2.6
RCP8.5

Both observations and simulations show an upward trend in mean annual temperature. Under a high emissions scenario, this trend is projected to continue until the end of the century, with a rise of 4.4°C on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 1.2°C on average

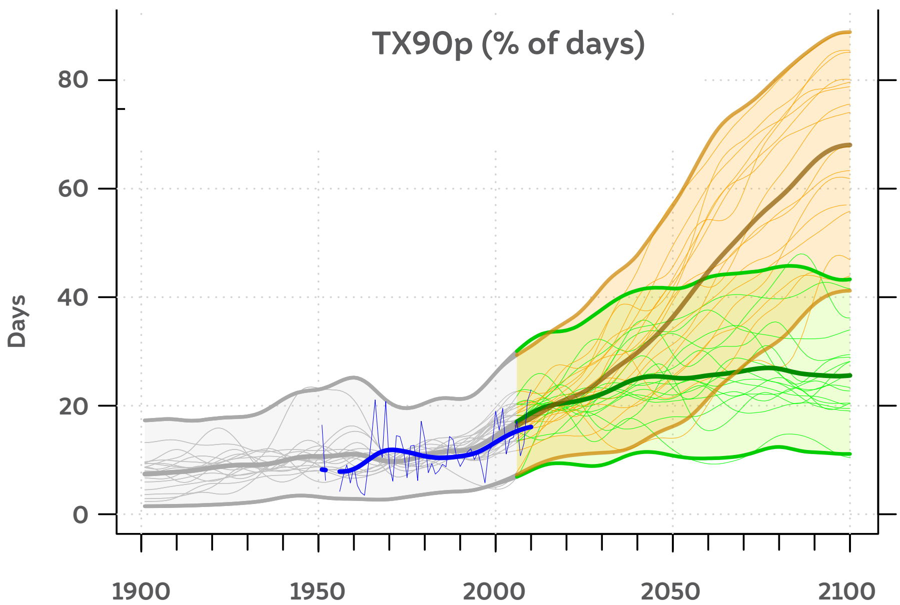


Figure D2
Increases in temperature extremes for Jabalpur

Source: Authors' analysis

Obs gridded
Historic
RCP2.6
RCP8.5

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 50 days on average from 1981-2010 to 2071-2100 under a high emissions scenario (and the number of heat wave days to increase by around 175 days on average). If emissions decrease rapidly, the rise in warm days is limited to about 15 days on average (and the rise in heat wave days is about 35 days on average).

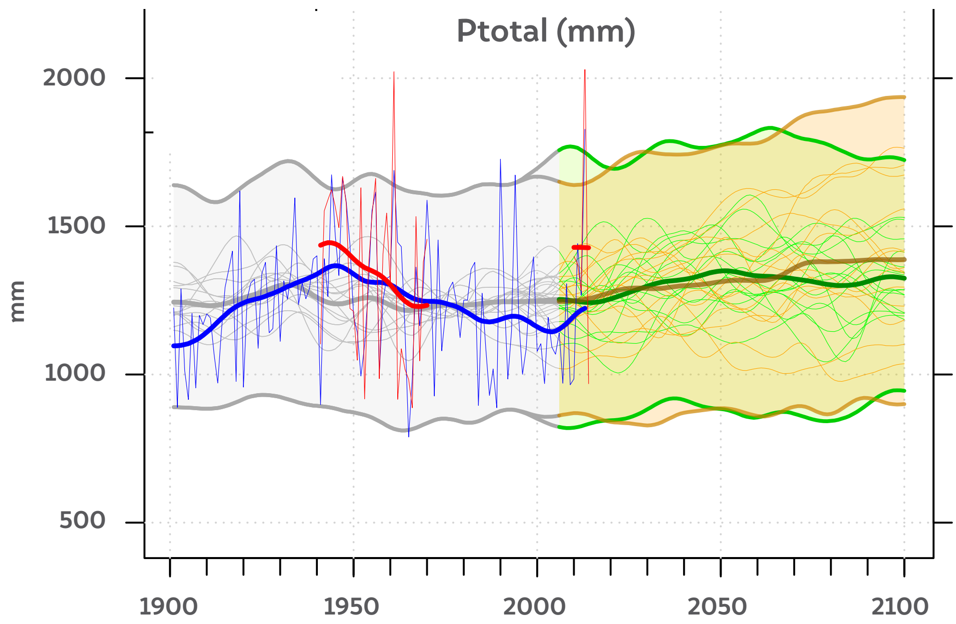


Figure D3
Increases in mean precipitation for Jabalpur

Source: Authors' analysis

The observations are dominated by large decade-to-decade and year-to-year variability. The simulations show a general tendency towards increasing total annual rainfall, although variability is large. Under a high emissions scenario, total annual rainfall is projected to increase by about 11 per cent (about 140mm) on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 70mm on average.

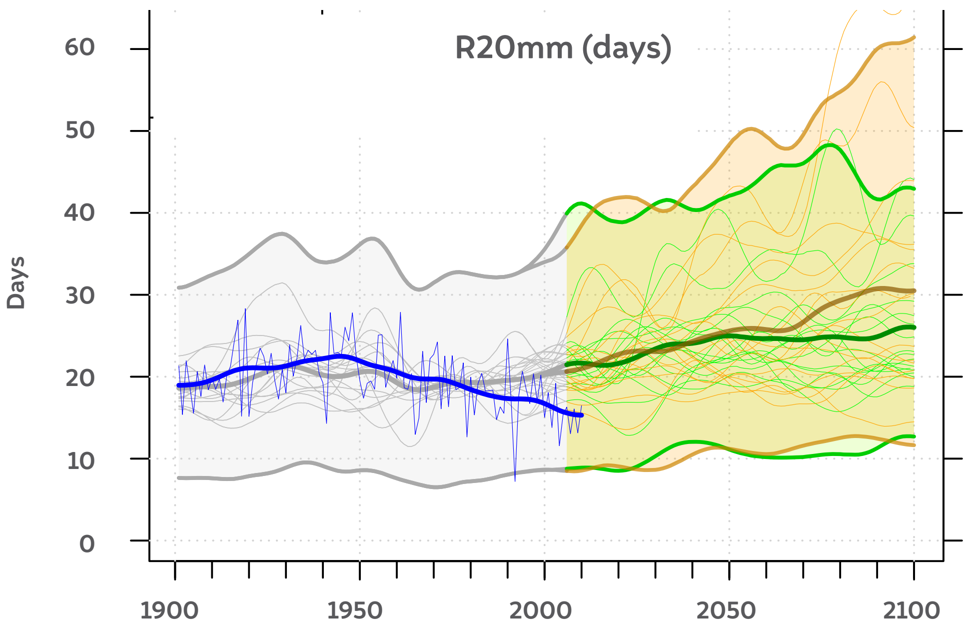


Figure D4
Number of heavy-rainfall days for Jabalpur

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 20mm (shown here), for example, is projected to increase by about 10 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 (perhaps even a slight increase with high emissions) from an average of about 85 days, with continuing large year-to-year variability.

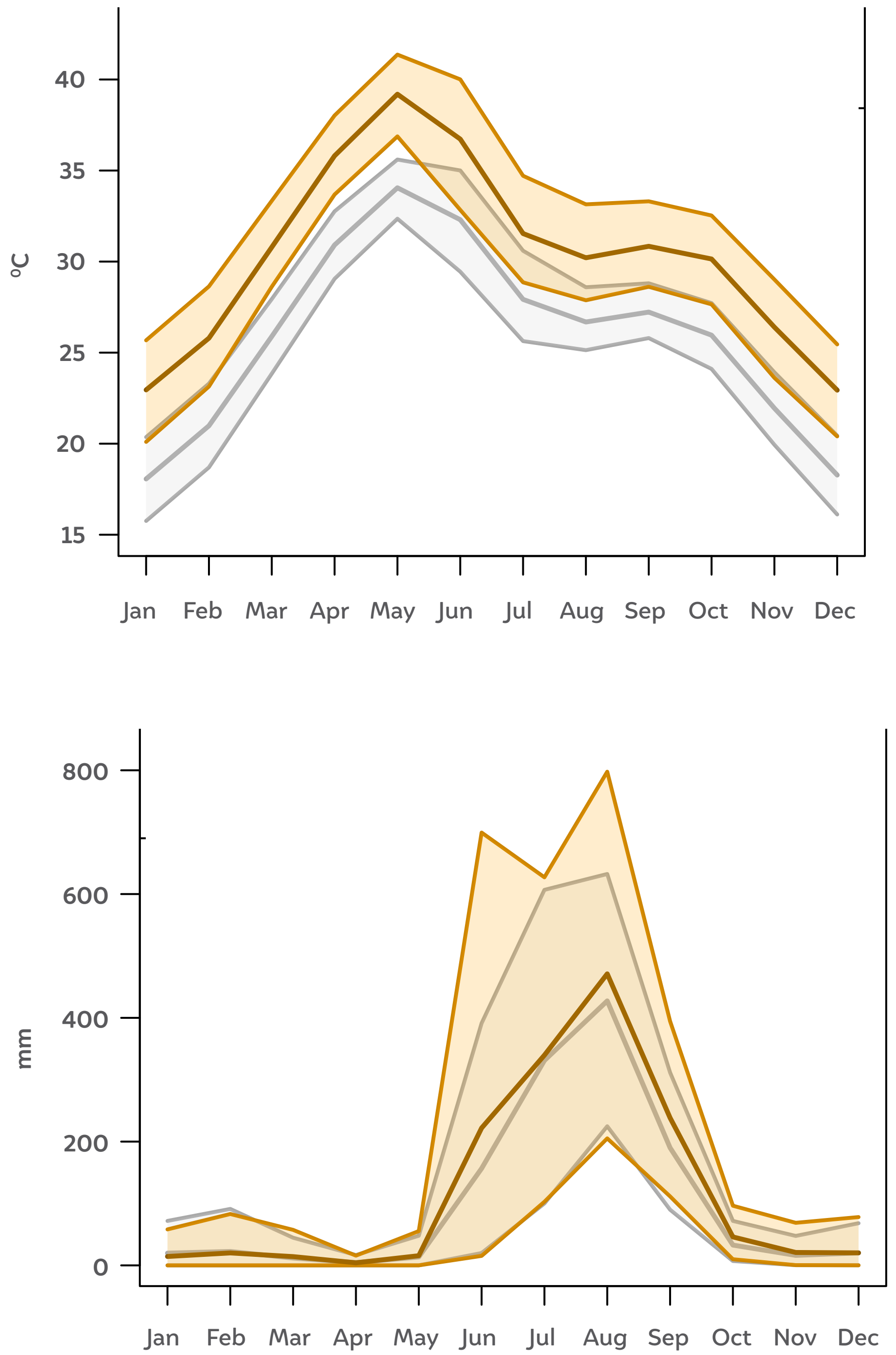


Figure D5
Simulated seasonal cycles of monthly temperature (top) and rainfall (bottom)

Source: Authors' analysis

1981-2010
2071-2100

These figures show the simulated seasonal cycles of mean monthly temperature (left) and total monthly rainfall (right) for 1981-2010 (grey) and 2071-2100 for the high RCP8.5 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 rainfall (August).

	Observed 1981-2010	2030s - RCP8.5	2050s - RCP8.5	2080s - RCP8.5	2080s - RCP2.6
Temperature					
Mean temperature	25.8°C	+1.4 (0.9 to 1.8) °C	+2.1 (1.4 to 2.7) °C	4.4 (3.2 to 5.4) °C	+1.2 (0.6 to 2.0) °C
Warm days	12 days	+14 (7 to 22) days	+23 (9 to 36) days	+49 (28 to 66) days	+13 (6 to 26) days
Warm nights	13 days	+22 (14 to 30) days	+34 (24 to 47) days	+62 (52 to 74) days	+17 (8 to 27) days
Rainfall					
Total rainfall	1158 mm	+4 (-10 to +13)%	+5 (-9 to +20)%	+11 (-12 to +31)%	+5 (-4 to +17)%
Heavy-rainfall days	17 days	+4 (-1 to +12) days	+5 (-1 to +16) days	+10 (-1 to +33) days	+5 (-1 to +17) days
Consecutive dry days	78 days	+2 (-6 to +13) days	+2 (-7 to +17) days	+5 (-15 to +23) days	0 (-11 to +9) days

Table D1
Observed and projected changes for temperature and rainfall for Jabalpur

Source: Authors' analysis

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 for Jabalpur

- The Jabalpur climate is subject to large year-to-year variability particularly for rainfall. Thus even in the absence of anthropogenic climate change, this Smart City needs to be resilient to this natural variability.
- Observed records for the Jabalpur region show emerging trends in temperature over the last few decades – in particular a clear trend towards higher temperatures and more frequent high temperature extremes.

- Climate projections show a strengthening of the observed temperature trends, particularly with higher greenhouse emissions, as well as a tendency towards higher rainfall totals and more intense and frequent rainfall extremes.
- If global warming can be constrained to 2°C or less with respect to preindustrial conditions, the impacts of climate change would be substantially reduced for Jabalpur, particularly in the second half of the century.

Table D2
Climate change and potential risks

Source: Authors' analysis

Projected climate changes	Potential impacts and risks
Warmer conditions, including more intense and 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. • Negative impacts and constraints on labour productivity, particularly on outdoor workers. • 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. • Possible implications for water balance and the quantity and quality of water resources (also taking into consideration the likely persistence of long dry spells and increased evaporation with warmer conditions).

Appendix E. Ujjain climate risk profile

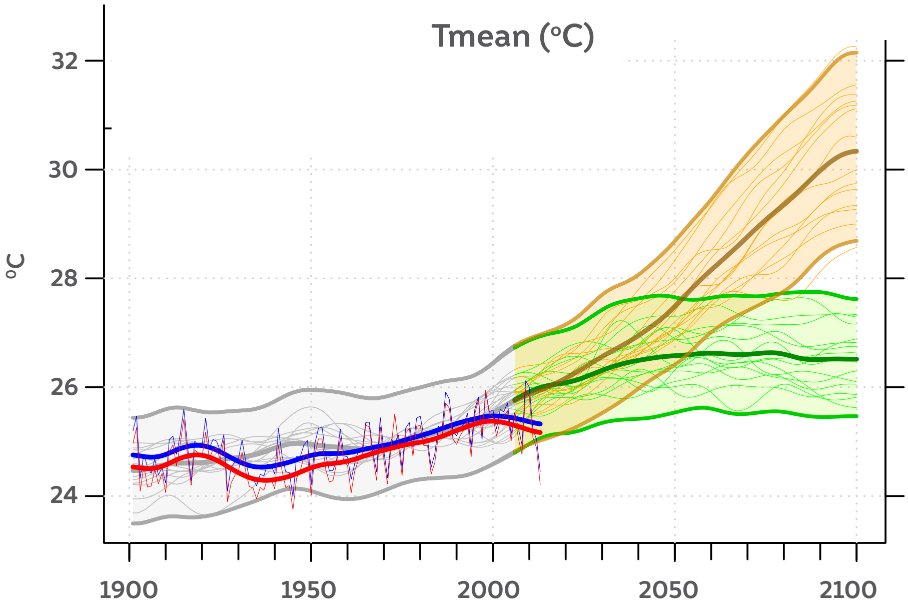


Figure E1
Increases in mean temperature for Ujjain

Source: Authors' analysis

Obs station
Obs gridded
Historic
RCP2.6
RCP8.5

Both observations and simulations show an upward trend in mean annual temperature. Under a high emissions scenario, this trend is projected to continue until the end of the century, with a rise of 4.3°C on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 1.1°C on average.

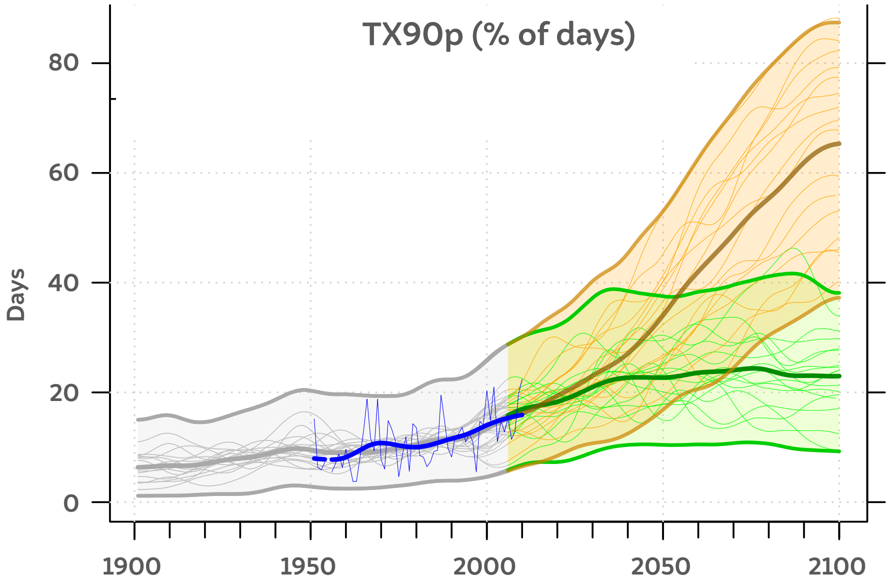


Figure E2
Increases in temperature extremes for Ujjain

Source: Authors' analysis

Obs gridded
Historic
RCP2.6
RCP8.5

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 45 days on average from 1981-2010 to 2071-2100 under a high emissions scenario (and the number of heat wave days to increase by around 165 days on average). If emissions decrease rapidly, the rise in warm days is limited to about 10 days on average (and the rise in heat wave days is about 30 days on average).

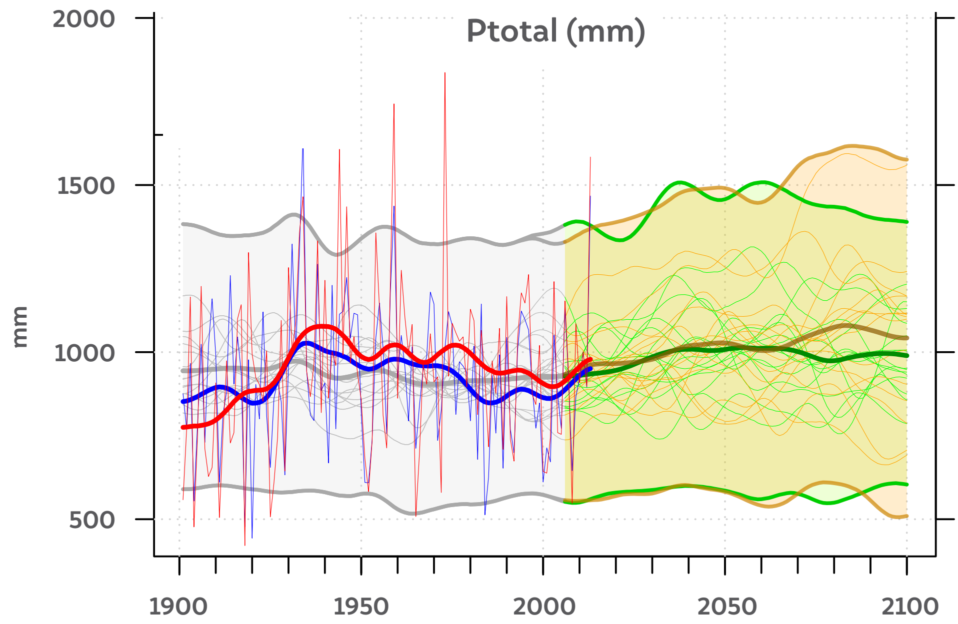


Figure E3
Increases in mean precipitation for Ujjain

Source: Authors' analysis

The observations are dominated by large decade-to-decade and year-to-year variability. The simulations show a general tendency towards increasing total annual rainfall, although variability is large. Under a high emissions scenario, total annual rainfall is projected to increase by about 15 per cent (about 145mm) on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 70mm.

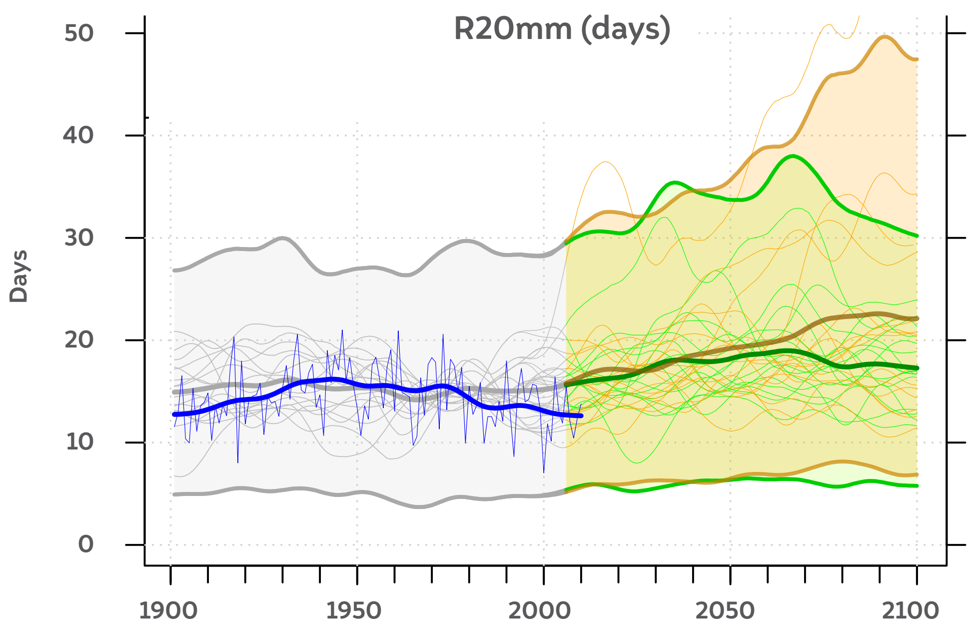


Figure E4
Number of heavy-rainfall days for Ujjain

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 20mm (shown here), for example, is projected to increase by about 7 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 (perhaps even a slight increase with high emissions) from an average of about 120 days, with continuing large year-to-year variability

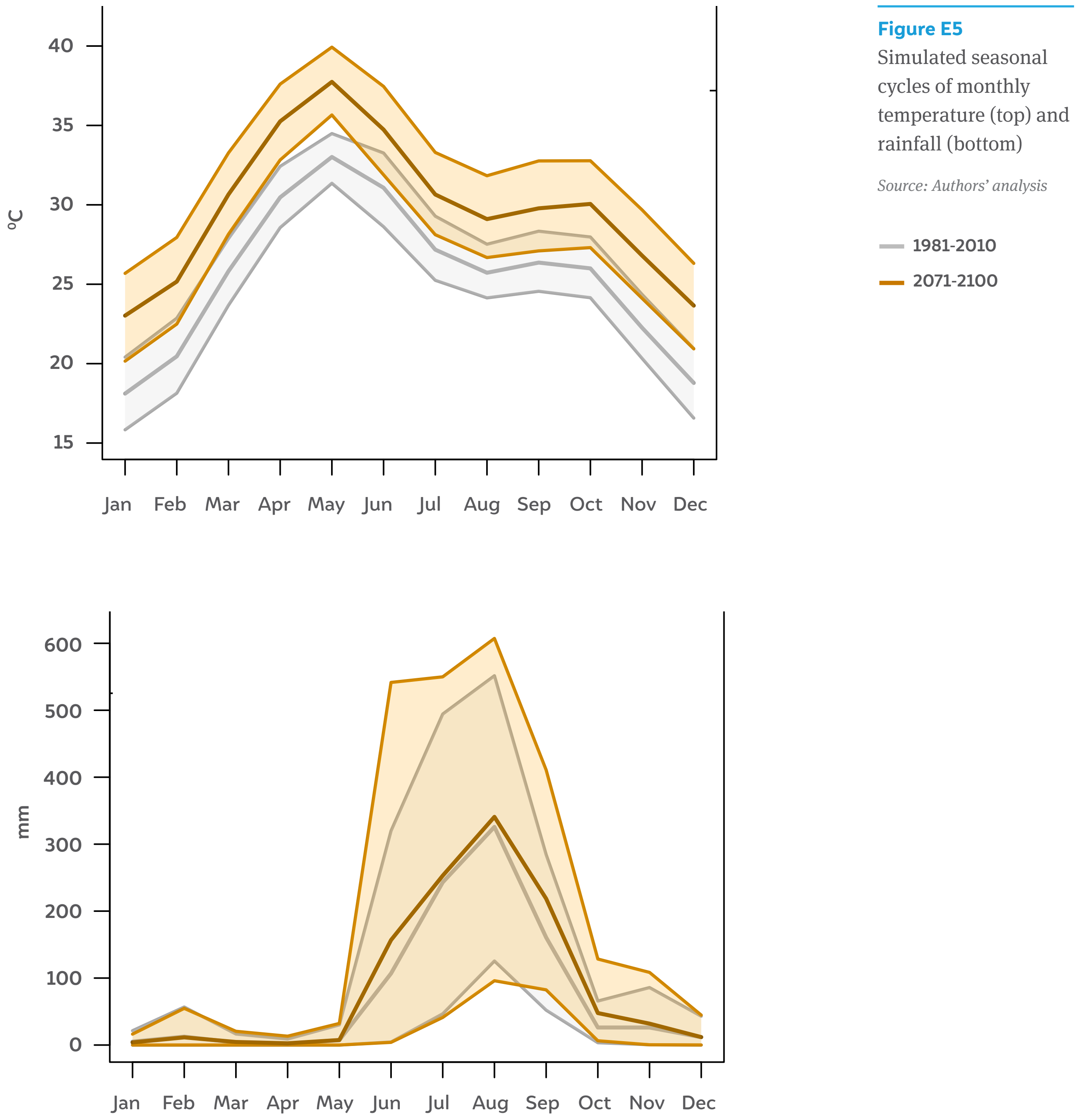


Figure E5
Simulated seasonal cycles of monthly temperature (top) and rainfall (bottom)

Source: Authors' analysis

These figures show the simulated seasonal cycles of mean monthly temperature (left) and total monthly rainfall (right) for 1981-2010 (grey) and 2071-2100 for the high RCP8.5 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 rainfall (August).

	Observed 1981-2010	2030s - RCP8.5	2050s - RCP8.5	2080s - RCP8.5	2080s - RCP2.6
Temperature					
Mean temperature	25.4°C	+1.3 (0.9 to 1.7) °C	+2.1 (1.5 to 2.7) °C	+4.3 (3.0 to 5.4) °C	+1.1 (0.5 to 1.8) °C
Warm days	13 days	+12 (6 to 19) days	+21 (10 to 32) days	+46 (28 to 64) days	+10 (3 to 20) days
Warm nights	13 days	+21 (13 to 28) days	+33 (21 to 44) days	+63 (50 to 75) days	+16 (6 to 26) days
Rainfall					
Total rainfall	860 mm	+8 (-4 to +22)%	+11 (-5 to +22)%	+15 (-13 to +39)%	+7 (-6 to +21)%
Heavy-rainfall days	13 days	+3 (0 to +8) days	+4 (0 to +13) days	+7 (0 to +22) days	+3 (-1 to +8) days
Consecutive dry days	107 days	+3 (-14 to +23) days	+4 (-18 to +25) days	+5 (-16 to +36) days	0 (-16 to +15) days

Table E1
Observed and projected changes for temperature and rainfall for Ujjain

Source: Authors' analysis

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 for Ujjain

- The Ujjain climate is subject to large year-to-year variability particularly for rainfall. Thus even in the absence of anthropogenic climate change, this Smart City needs to be resilient to this natural variability.
- Observed records for the Ujjain region show emerging trends in temperature over the last few decades – in particular a clear trend towards higher temperatures and more frequent high temperature extremes.

- Climate projections show a strengthening of the observed temperature trends, particularly with higher greenhouse emissions, as well as a tendency towards somewhat higher rainfall totals and more intense and frequent rainfall extremes.
- If global warming can be constrained to 2°C or less with respect to preindustrial conditions, the impacts of climate change would be substantially reduced for Ujjain, particularly in the second half of the century.

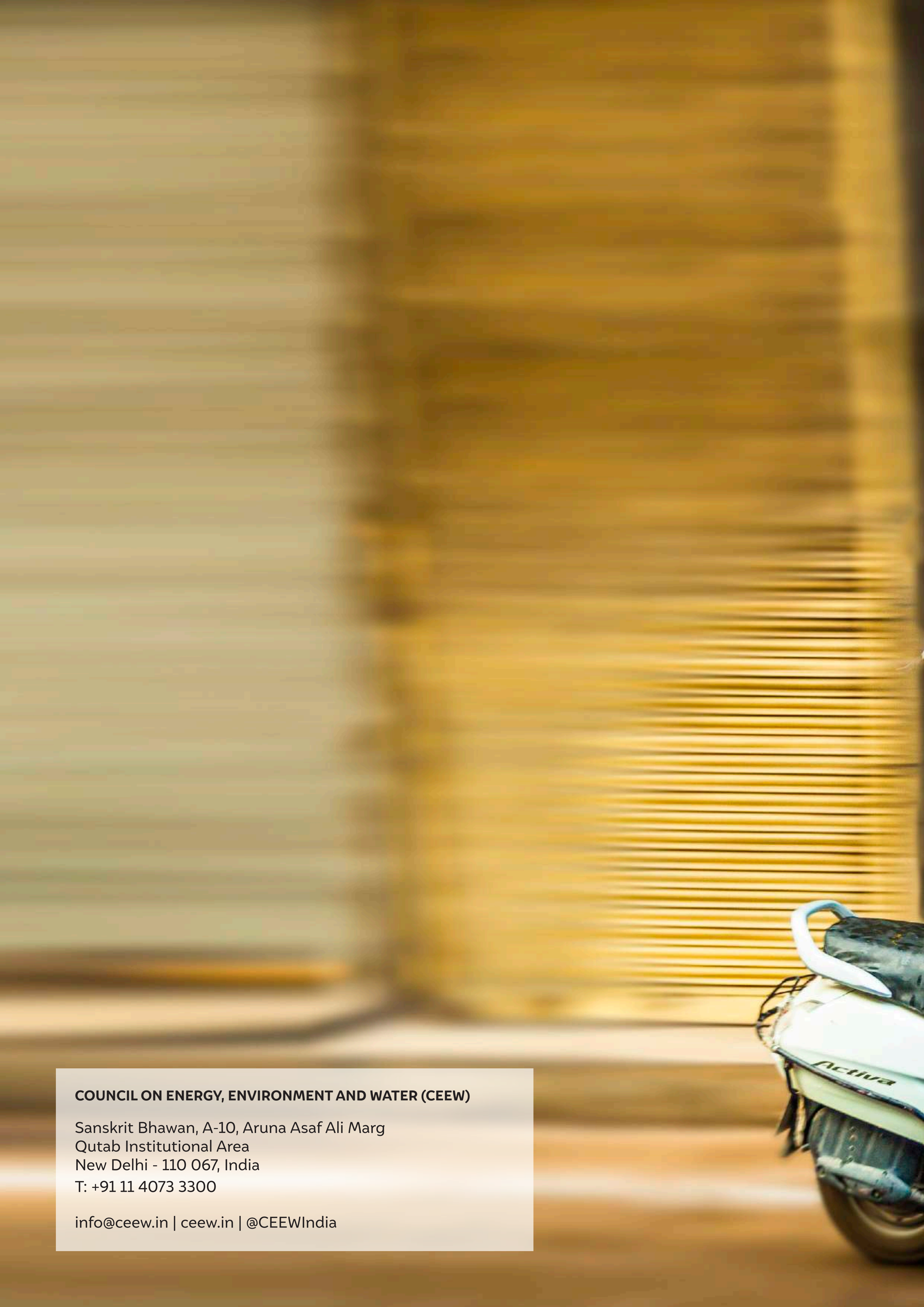
Table E2
Climate change and potential risks

Projected climate changes	Potential impacts and risks
Warmer conditions, including more intense and 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. • Negative impacts and constraints on labour productivity, particularly on outdoor workers. • 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. • Possible implications for water balance and 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

Indian cities will need to anticipate and respond to climate risks, if they want to be future engines of growth.

Image: Pexels



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