CLIMATE CHANGE ASSESSMENT

I. BASIC PROJECT INFORMATION

Project Title:	IND (53326-001) Bengaluru Metro Rail Project
Project Cost ($ million):	1,055.8
Location:	Bengaluru, Karnataka, INDIA
Sector / Subsector:	Transport / Urban public transport
Brief Description:	Extension of metro rail network is proposed to (i) alleviate congestion in the city center and along arterial roads, (ii) connect the airport, and (iii) promote use of public transport. The main output of the project will be new metro lines of 56 kilometers constructed. The two new metro lines are termed as Phase 2A and Phase 2B of the Bengaluru Metro. Phase 2A will improve connectivity among different metro lines and with railways at two junction stations along the Outer Ring Road, while Phase 2B will connect the city center with the airport. With the proposed lines, network coverage and density of Bengaluru Metro will be increased substantially, and the metro will offer more convenient services to users. Multimodal facilities will be developed at metro stations including car and motor pool, bus bay, and taxi pool, as well as pedestrian bridges, which will enable smooth inter-modal connectivity and provide better last mile connectivity. It is important to consider climate change in the expansion project. High temperatures may cause rail tracks to expand and buckle. More frequent and severe heat waves may require track repairs or speed restrictions to avoid derailments. Heavy precipitation could also lead to delays and disruption, and tropical storms and cyclones can also flood or leave debris on railways, disrupting rail travel. Damages from flooding may require rail lines to be rebuilt or raised in future expansion projects.

II. SUMMARY OF CLIMATE CHANGE FINANCE

Project Financing		Climate Finance	
Source	**Amount** ($ million)	**Adaptation** ($ million)	**Mitigation** ($ million)
ADB Resources			
Ordinary Capital Resources (OCR)	500.0	1.47	498.53
Concessional OCR lending			
Asian Development Fund Grant			
Cofinancing	Not applicable	Not applicable	Not applicable

Source: Asian Development Bank.

III. SUMMARY OF CLIMATE RISK SCREENING ASSESSMENT

A. Sensitivity of Project Components to Climate/Weather Conditions and Geological Hazards

Project Component. Construction of 56 kilometers of new metro lines, mostly elevated (viaduct structures and most stations) with very short at-grade segments.

Sensitivity. Climate change raises very concrete challenges for the project. With majority of the lines being elevated, structures are exposed to excessive heat, causing damage and disruption of rail operations. High temperatures may cause rail tracks to expand and buckle. More frequent and severe heat waves may cause derailments and require track repairs or speed restrictions. Heavy precipitation could also lead to delays and disruption, and tropical storms and cyclones can also flood or leave debris on railways, disrupting rail travel. Damages from flooding may require rail lines to be rebuilt, particularly along at grade portions, or raised in future expansion projects. Impacts on passenger comfort also raise additional problems.

B. Climate Risk Screening

Projected temperature increase Annual and monthly average temperature, minimum and maximum temperatures projected to increase (Special Report on Emissions Scenarios [SRES] A1B and Representative Concentration Pathway [RCP] 2.6. and RCP 8.5 all point to an increasing trend).	**Medium**
Projected change in average precipitation (Monthly precipitation is highly variable)	**Low**
Extreme events (Heat waves and extreme rainfall episodes leading to floods/droughts) Relatively increasing number of hot days (greater than 40ºC) is expected in March to June. Rainfall is mostly increasing during the monsoon season. Water scarcity, which is an identified risk for the area, may also be exacerbated.	**Medium**
Cyclones Frequency of the most intense tropical cyclones possible to increase in the area already identified at risk	**High**

Climate Risk Classification: MEDIUM

C. Climate Risk and Adaptation Assessment

1. Based on the Climate Risk and Vulnerability Assessment (CRVA) prepared for the project, primary climate change risks that can impact the project in the short to medium term are temperature increase and variability of rainfall, particularly the increases during the monsoon seasons.
2. Observed trends in the state show a slight increase in annual maximum and mean temperatures, which are also reflected in future projections (SRES A1B and RCPs 2.6 and 8.5) of annual and monthly average temperature, and minimum and maximum temperatures.
3. Long-term climate change risks that could impact projects are flooding from extreme rainfall events, particularly during monsoon periods, and increases in annual average temperature in the project area that could increase the risk of extreme hot days. Heat waves and flooding appear as priority threats, particularly urban flooding as a result of increase in impermeable surfaces due to rapid urbanization.
4. Storms and more frequent strong cyclones can bring about increased flooding, greater probability of infrastructure failures, erosion of rail track foundation and bridge supports, bridge scour, reduced clearance under bridges, wind damage to roofs of stations, lighting, overhead cables, rail signals, and other tall structures. Power outages during such events will also hamper operations.
5. The increase in frequency and magnitude of extreme heat conditions in turn increases the risk of failures due to track expansion. Pervasive changes induced by extreme heat may also lead to deformations and failure of reinforced cement concrete structures. Abrupt temperature changes can cause cracking and spalling of concrete due to thermal shock, and aggregate expansion can also produce distress within the concrete.
6. Adaptation may involve additional investments on design and materials, use/installation of new technologies, and improved operation and maintenance.

D. Climate Risk Screening Tool/Procedure Used (specify)**:**
South Asia Department (SARD) climate risk screening framework and methodology

IV. CLIMATE ADAPTATION PLANS WITHIN THE PROJECT

Adaptation Activity	Target Climate Risk	Estimated Adaptation Finance ($ million)	Adaptation Finance Justification
1. Rainwater harvesting and recharge pits at stations and viaducts of the alignment Construction of recharge pits along the median at each pier location and within depots and stations to facilitate percolation of runoff into the ground per approved design by the Central Water Board	Increased precipitation resulting in flooding; exacerbated urban flooding due to increased impermeable surface	1.11	Inclusion of rainwater harvesting and recharge pits at all pier locations will entail additional civil works costs.
2. Prevention of overland flood water ingress for 800-meter section of "cut-and-cover" tunnel at Yelanhanka under line 2B Waterproofing of tunnel walls, parapet walls at ramp sections, incorporate interior drainage, sump and pumping system	Increased precipitation resulting in flooding; exacerbated urban flooding due to increased impermeable surfaces	0.36	Measures required to prevent flood waters entering from ramp and at gaps between tunnel sections
The Asian Development Bank is financing 100% of the total civil works cost equivalent to $1.47 million.			

V. CLIMATE MITIGATION PLANS WITHIN THE PROJECT

Mitigation Activity	Estimated GHG Emissions Reduction (tCO_2e/year)	Estimated Mitigation Costs ($ millions)	Mitigation Finance Justification
Construction of mostly elevated medium capacity metro line	40,454 (detailed computation and assumptions are in Appendix 1)	498.53	Availability of a more efficient mode of public transport will cause the public to shift from more polluting road-based public and private transport resulting in reduced overall emissions.

GHG = greenhouse gas, tCO_2e = tons of carbon dioxide equivalent.
Source: Asian Development Bank.

Greenhouse Gas Emissions Reduction Calculation*

Year	Annual Ridership		Emission Savings Due to Modal Shift (tCO2/year)		Emissions from Operation (tCO2/year)		Net Emission Savings (tCO2/year)		Total Emission Savings (tCO2/year)
	Phase 2A	**Phase 2B**	**Phase 2A**	**Phase 2B**	**Phase 2A**	**Phase 2B**	**Phase 2A**	**Phase 2B**	
2025	24,241,139	26,073,697	9,788	10,528	13,483	22,949	-3,694	-12,421	-16,115
2026	50,474,900	54,290,652	20,381	21,922	15,098	26,025	5,283	-4,103	1,180
2027	78,824,127	84,782,997	31,829	34,235	16,677	29,031	15,151	5,204	20,355
2028	82,063,799	88,267,578	33,137	35,642	16,677	29,031	16,459	6,611	23,070
2029	85,436,621	91,895,375	34,499	37,107	16,677	29,031	17,821	8,076	25,897
2030	88,948,066	95,672,275	35,917	38,632	16,677	29,031	19,239	9,601	28,840
2031	92,603,831	99,604,406	37,393	40,220	25,295	43,250	12,098	-3,030	9,068
2032	96,409,849	103,698,147	38,930	41,873	25,295	43,250	13,635	-1,377	12,258
2033	100,372,294	107,960,141	40,530	43,594	25,295	43,250	15,235	344	15,579
2034	104,497,595	120,891,063	42,195	48,815	25,295	43,250	16,901	5,565	22,466
2035	108,792,446	125,859,685	43,930	50,821	25,295	43,250	18,635	7,572	26,207
2036	113,263,815	131,032,518	45,735	52,910	25,295	43,250	20,441	9,661	30,101
2037	117,918,958	136,417,955	47,615	55,085	25,295	43,250	22,320	11,835	34,155
2038	122,765,427	142,024,733	49,572	57,349	25,295	43,250	24,277	14,099	38,376
2039	127,811,087	147,861,949	51,609	59,706	25,295	43,250	26,315	16,456	42,771
2040	133,064,122	153,939,075	53,730	62,160	25,295	43,250	28,436	18,910	47,346
2041	138,533,058	160,265,971	55,939	64,714	29,603	51,015	26,336	13,699	40,035
2042	144,226,766	166,852,903	58,238	67,374	29,603	51,015	28,635	16,359	44,994
2043	150,154,486	173,710,557	60,631	70,143	29,603	51,015	31,028	19,128	50,157
2044	156,325,836	180,850,061	63,123	73,026	29,603	51,015	33,520	22,011	55,531
2045	162,750,828	188,282,998	65,718	76,027	29,603	51,015	36,115	25,012	61,127
2046	169,439,887	196,021,430	68,419	79,152	29,603	51,015	38,816	28,137	66,953
2047	176,403,866	204,077,910	71,231	82,405	29,603	51,015	41,628	31,390	73,018
2048	183,654,065	212,465,513	74,158	85,792	29,603	51,015	44,555	34,777	79,332
2049	191,202,247	221,197,845	77,206	89,318	29,603	51,015	47,603	38,303	85,906
2050	199,060,659	230,289,077	80,379	92,989	29,603	51,015	50,776	41,974	92,751
TOTALS	3,199,239,772	3,644,286,512	1,291,832	1,471,539	644,267	1,107,744	**647,565**	**363,795**	**1,011,360**
					Average per annum:		25,903	14,552	40,454

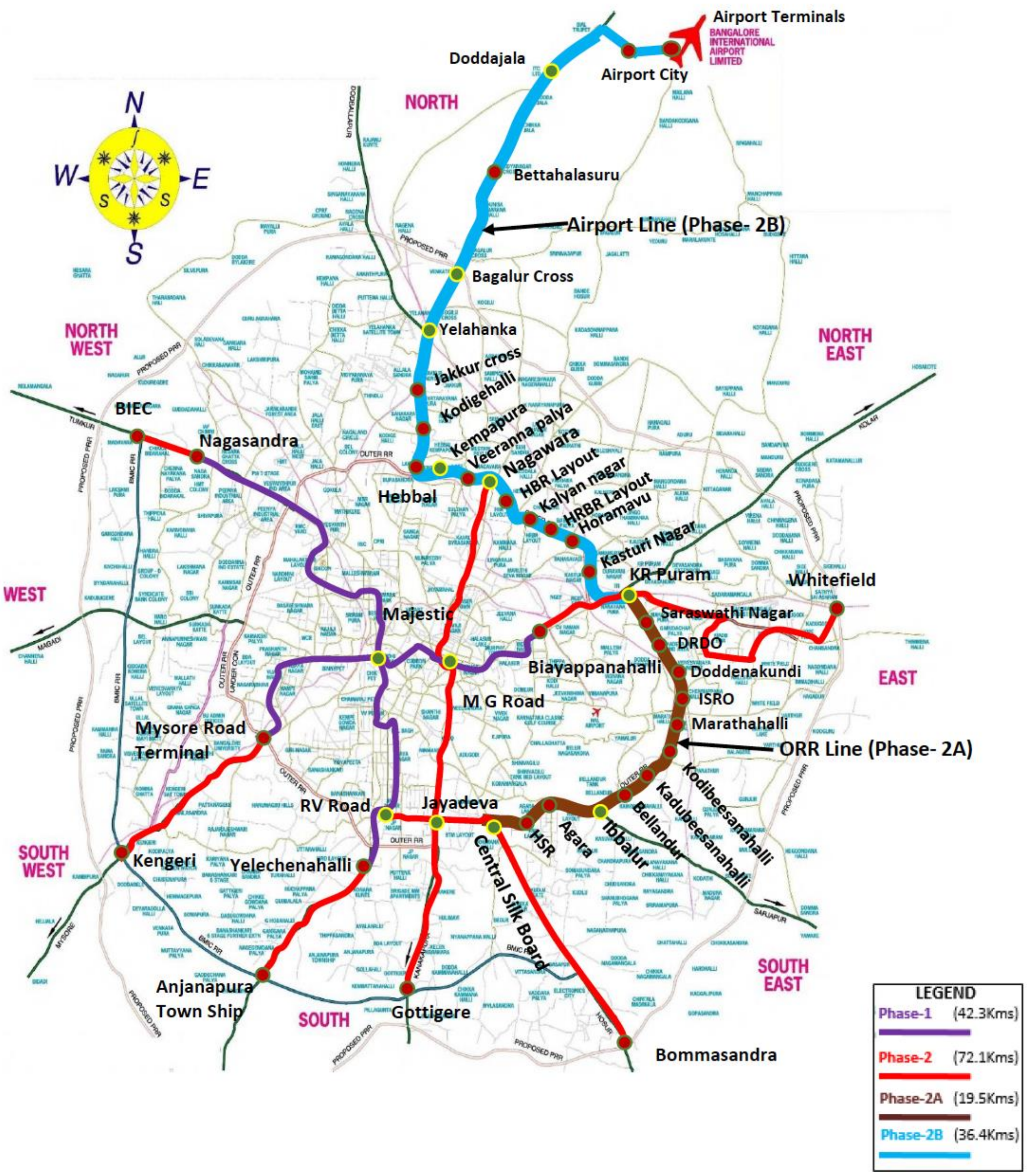
tCO2 = tons of carbon dioxide.

***Assumptions:**

1. Annual ridership numbers are consistent with the financial and economical assessments of the project and are based on the detailed project reports from October 2019 with the following modifications to the estimation:
   - 2 kilometer (km) catchment area instead of 5 km
   - Longer construction period by 1 year
   - Ramp-up period in initial 3 years
2. Carbon dioxide (CO_2) emission savings are based on modal shift of passengers from road-based transport to the metro taken from the Comprehensive Mobility Plan, October 2019 with the following percentages:
   - Car/taxi: 21%
   - Two-wheeler: 24%
   - Auto rickshaw: 8%
   - Bus: 48%
3. Emissions from power generation necessary for metro operation have been deducted from the CO_2 emission savings. Electricity consumption of train operation is dependent on line length and number of trips per day. Electricity consumption of stations and depots is calculated as a fixed amount over the lifetime of the project.
4. Pollution is expected to be reduced primarily due to reduction in number of vehicles on road owing to the shift of passengers to the metro. The emission by vehicle type of CO_2 in grams per km was taken following the Ministry of Housing and Urban Affairs guidelines. Multiplying these factors to the total vehicle kilometers (per vehicle type) taken off the roads as passengers shift to the metro gives the value of the total benefit from a reduction in vehicular emissions.
5. Weighted average emissions factor used to derive emissions from train operations was taken from the Central Electricity Authority 2018 calculations multiplied by the projected metro train energy consumption from the detailed project report, which is 15 kilowatt-hour (KWh)/ton-kilometer (Tkm) for Phase 2A and 16.34 KWh/Tkm for Phase 2B. The energy used by the metro line is based on the actual energy consumption for the East–West Corridor, with a frequency of 3 minutes during peak hours (or 6 hours) and a frequency of 10 minutes for 12 hours.
6. The calculation method does not differentiate for the actual number of passengers in the metro line and therefore the actual weight of the train. The energy use in the early years of operation (not operating at full capacity) might therefore be overestimated and thus the net CO_2 savings might be underestimated.

CLIMATE RISK AND VULNERABILITY REPORT

India: Bengaluru Metro Rail Project



April 2020

ABBREVIATIONS

ADB	–	Asian Development Bank
asl	–	above sea level
amsl	–	above mean sea level
BCCI-K	–	Bengaluru Climate Change Initiative-Karnataka
BMRCL	–	Bengaluru Metro Rail Corporation Limited
CRVA	–	climate risk and vulnerability assessment
DPR	–	detailed project report
INR	–	Indian rupee
IPCC	–	Intergovernmental Panel on Climate Change
km	–	kilometer
km^2	–	square kilometer
m	–	meter
mm	–	millimeter
RCP	–	representative concentration pathway
SRES	–	Special Report on Emissions Scenarios
CCKP	–	Climate Change Knowledge Portal

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FIGURES

I. INTRODUCTION

A. Background

1. Bengaluru (formerly Bangalore), the capital city of the State of Karnataka, is one of the fastest growing metropolises in India with a population of over 12 million people. The Bengaluru Metropolitan Area covers an area of approximately 1,284 square kilometers (km^2) and is located in the southern Deccan plateau at an altitude of around 900 meters (m) above mean sea level (amsl). Bengaluru has a tropical savanna climate (Köppen climate classification Aw) with distinct wet and dry seasons. Due to its elevation, Bengaluru usually enjoys a moderate climate throughout the year, although occasional heat waves make summer somewhat uncomfortable.

2. The detailed project reports (DPRs) for the proposed Phase 2A[1] and Phase 2B[2] of the Bengaluru Metro expansion project indicate that traffic congestion in the city is increasingly becoming problematic due to the increased ownership and use of automobiles, negatively impacting the quality of life and mobility in the city. The cost of traffic congestion is extremely high as it results in increases in journey times, fuel consumption, other operating costs, and environmental pollution. Today, Bengaluru's road network, totaling some 14,000 kilometers (km) of the roads, is highly strained due to rapid urbanization and riddled with traffic jams, increased road accidents, and road usage conflicts.

3. The existing surface transportation infrastructure in Bengaluru is composed of a ring–radial pattern of roads that radiates outwards from the center of the city. Between 2008 and 2018, the number of vehicles registered in Bengaluru increased from 3.24 million to 7.406 million, with vehicle ownership rapidly on the rise from 284 vehicles per thousand persons in 2001 to 419 vehicles in 2011, and to an estimated 640 vehicles in 2018. Urbanization has seriously limited road-widening prospects in the city where right-of-way widths are limited to just 10 m in 43% of the total road length and a meager 13% of the roads with right-of-way widths between 20 m and 30 m.

4. Aside from the city's road transport network, two metro rails with a total length of 43.2 km are in operation and designated as Reach 1 and 2 along the East–West Corridor with a total length of 18.1 km, and Reach 3 and 4 along the North–South Corridor with a total length of 24.2 km. The average daily ridership of the metros in the two corridors was recorded to be 405,000 in October 2019. These existing metros operate with three car-trains that run completely packed during the peak hours. As such, the Bengaluru Metro Rail Corporation Limited (BMRCL) is now introducing six car-trains in a phased manner to improve the capacity through increased ridership. At the moment, 32.025 km of extensions to the East–West and North–South corridors and additional two new lines with a total length of 40.07 km designated as Reach 5 and 6 are under construction.

5. A summary of the status of current metro networks of Bengaluru, both operational and under construction, is provided in Table A3.1.

[1] Bengaluru Metro Rail Corporation Limited. 2019. ORR Metro Line on Outer Ring Road from Central Silk Board (CSB) Junction to KR Puram. Detailed Project Report (DPR) for Phase 2A of Bengaluru Metro. Volume I. October (Revised).
[2] Bengaluru Metro Rail Corporation Limited. 2019. From KR Puram to Kempegowda International Airport. Detailed Project Report (DPR) for Phase 2B of Bengaluru Metro. Volume I. October (Revised).

Table A3.1: Status of Current Metro Networks in Bengaluru

#		Corridor Details	Length (km)	Status
Phase 1	1	Baiyappanahalli to Mysore Road (East–West Corridor- Purple Line) Reach 1 & Reach 2	18.1	Operational
	2	Nagasandra to Yelachenahalli (North- South Corridor- Green Line) Reach 3 & Reach 4	24.2	
Phase 2	1	N-S Line Extension from Puttenahalli Cross to Anjanapura Township Reach 4B	6.29	Under Construction
	2	N-S Line Extension from Hesarghatta Cross to BIEC Reach 3C	3.77	
	3	E-W Line Extension from Baiyappanahalli to ITPL Whitefield Reach 1A, Reach 1B	15.5	
	4	E-W Line Extension from Mysore Road Terminal to Kengeri Reach 2A , Reach 2B	6.465	
	5	New N-S Line IIMB to Nagawara Reach 6	21.25	
	6	New E-W Line to R.V.Road to Bommasandra Reach 5	18.82	

E-W = east–west, N-S = north–south.
Source: Bengaluru Metro Rail Corporation Ltd.

6. To meet the challenges of a rapidly expanding city and to help ease the difficulties faced by urban and periphery commuters, a comprehensive traffic and transportation study for Bengaluru Metropolitan Region was conducted in 2015. The major outcome of the study was the identification of project proposals for implementation with the aim of addressing transportation needs in the short-, medium-, and long-term horizons. As a long-term measure, the development of some 341 km of mass transit systems covering major corridors of movement in the city and interchange facilities with other modes of transport has been identified.

7. The Government of India has requested assistance from the Asian Development Bank (ADB) to support the development of two of its planned mass transport systems in Bengaluru that requires the construction of metro rail transport infrastructures designated as (i) Phase 2A that will connect Central Silk Board to KR Puram, and (ii) Phase 2B that will connect KR Puram to Kempegowda International Airport. The plan of the Bengaluru metro systems showing these proposed metro projects, Phase 2A with a total length of 19.45 km and Phase 2B with a total length of 36.4 km, is on the cover page of this report.

8. The metro project is in line with ADB Strategy 2030 under the following operational priorities: (i) making cities more livable; (ii) strengthening governance and institutional capacity; (iii) accelerating progress in gender equality; and (iv) tackling climate change, building climate and disaster resilience, and enhancing environmental sustainability.

9. As per requirements of ADB, aside from environmental and social safeguards, a climate risk and vulnerability assessment (CRVA) is done during the project preparation phase to examine climate change events and risks and, where appropriate, technical and economic feasibility of climate change adaptation measures.

10. The Bengaluru Metro Rail Corporation Limited is the executing agency of the proposed metro rail projects. In compliance with the 2017 Metro Rail Policy of the Government of India, the DPRs for Phase 2A and Phase 2B metro lines have been completed by the BMRCL in October 2019 through a series of consultations with relevant agencies of the Government of Karnataka.

B. Climate Change Plan and Policy of Karnataka

11. The Karnataka State Climate Plan process resulted from the central government directive in 2008 that all Indian states initiate a state action plan on climate change. With the aim of mainstreaming climate change in the Karnataka state's development planning, three independent but parallel documents, each following their own distinct procedures, were produced for Karnataka.

12. The official plan prepared through a state government-led process was produced by the Environmental Management and Policy Research Institute (EMPRI), an autonomous body under the Department of Forest, Ecology and Environment, Government of Karnataka. However, it is reported[3] that EMPRI did not have the requisite capacity to draft the plan and could bring only nominal expertise to bear on the topic, an opinion consistent with the research conducted in their study. The other two bodies that independently produced a state action plan were the Bengaluru Climate Change Initiative-Karnataka (BCCI-K) and another non-governmental body, the Centre for Sustainable Development.

13. The BCCI-K process was the earliest (May 2011) of the three and was more focused on a scientific assessment of the likely implications of climate change than the other two plans. The state action plan developed by BCCI-K relied on renowned research institutions to apply climate models and develop district-level predictions of climate variability for the state, a process facilitated by international technical and financial linkages. Starting with greenhouse gas inventory for the state, the impacts of climate change in vital sectors such as forests, agriculture, and water resources are presented in the BCCI-K action plan along with an analysis of socioeconomic vulnerability and adaptive capacity assessments.

14. The Karnataka Climate Change Action Plan[4] (KCCAP) adopted the BCCI-K climate change projections for Karnataka state. The BCCI-K projections used simulation data from the global climate model, HadCM3, from the Hadley Centre in the United Kingdom. Climate change projections for daily values of temperature (mean, maximum, and minimum) and daily values of precipitation were derived at grid-spacing of 0.44250 latitude by 0.44250 longitude and for Special Report on Emissions Scenarios (SRES) A1B midterm (2021–2050) emissions scenario relative to the baseline period 1961–1990.

II. PROJECT AREA DESCRIPTION

A. General Geography and Climate

15. Bengaluru Urban has an aerial coverage of about 2,174 km^2 and is situated within the north latitude of 12º39'32'' and 13º14'13'' and east longitude of 77º19'44'' and 77º50'13''. The area falls in southern Karnataka plateau that has a general elevation of 600 m–900 m amsl. Bengaluru sits on one of the world's oldest exposed rocks called peninsular gneiss, a type of metamorphic rock, while the soils in the city consist of red laterite and fine red loamy to clayey soils. In terms of seismicity, Bengaluru falls within seismic zones II and III of the Indian subcontinent, which has experienced quakes of magnitude as high as 6.4.

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[3] Anu Jogesh and Dubash, Navroz K. 2014. An Analysis of Karnataka's Action Plan on Climate Change. February.

[4] Environmental Management & Policy Research Institute (EMPRI) and The Energy and Resources Institute. 2013. Karnataka Climate Change Action Plan (KCCAP), First Assessment, 2012.

16. Bengaluru has two unique topographic terrains—North Bengaluru taluk,[5] which is a flat plateau, and the South Bengaluru taluk, which is characterized by undulating terrain. The middle of the taluk is a prominent ridge running north–northeast to south–southwest with gentle slopes and valleys on either side of this ridge. Although the Cauvery River basin encompasses a significant part of the southern Karnataka plateau, there are no major rivers flowing through Bengaluru Urban area except for a minor river, Vrishabhavathi, a tributary of the Arkavathi, which also flows through the city. Both rivers, Arkavathi and Vrishabhavathi, carry much of Bengaluru's sewage. Bengaluru has a good number of shallow water bodies varying in size from small ponds to lakes of considerable extents.

17. Bengaluru has a tropical wet and dry or savanna climate (Köppen climate classification Aw) with distinct wet and dry seasons. Situated in the Deccan plateau at an average altitude of around 900 m amsl, Bengaluru generally enjoys a moderate climate throughout the year with occasional heat wave conditions. April is the hottest month with temperature rising up to 35°C during the day and 21°C at night. December to January is the winter season with a maximum average temperature of 26°C and a minimum average temperature of 15°C. Although January is the coldest month, the temperature rarely drops below 10°C.

18. Over the past decade, the climate of Bengaluru is observed to have changed as a result of rapid urbanization and heat island effect, increasing pollution, and obliteration of vegetation and water bodies. The maximum temperature in Bengaluru Urban has risen to as high as 38°C to 39°C during April–May while in earlier decades it hardly exceeded 35°C.

19. The mean annual rainfall is around 875 millimeters (mm) spread over about 50 days in a year. Over half of the rainfall comes during the late monsoon months of August to October. Cyclonic rains occur during November and December while there is virtually no rainfall during January–March. Bengaluru receives both southwest as well as northeast monsoons.

B. The Project Corridors

20. Mass transit rail systems are planned on set standards and parameters that require large amounts of exploitable land for track alignment routes, including all other allied structures such as the stations, parking facilities, traction substations, communication towers, etc. Land availability is a major challenge in Bengaluru as land is scarce and costly, and any acquisition of private land can be a complex and lengthy process. Under such constraints, the usual course of action is keeping land acquisition to a minimum where either underground or aboveground rail systems are designed.

21. As seen in the layout map on the cover page of this report, both the proposed 19.45 km Phase 2A of metro line from Central Silk Board to K.R. Puram and the 26.4 km Phase 2B from K.R. Puram to Kempegowda International Airport are located within the city. Like all mega-cities, the Bengaluru urban sprawl is composed of vast expanses of built-up areas with complex land use patterns. This presents serious challenges to any on-land at-grade expansion of the city transport networks, be it rail or road.

22. The proposed Phase 2A metro line from Central Silk Board junction to K.R. Puram is planned along the city's Outer Ring Road, which has a 6-lane carriageway with service roads on either side. The total road width in this corridor is about 45 m throughout that is ideal for an elevated metro line. The width of the median is about 1.5 m that can accommodate construction

[5] Taluk is an Indian term for administrative division.

of the metro piers without compromising the existing road width. As the metro track follows the fairly flat road profile, there would be no steep gradients in the alignment. Track supporting structures on elevated sections are proposed for a vertical clearance of 5.50 m above road level for vehicular traffic.

23. The proposed Phase 2B metro line from K.R. Puram to Kempegowda International Airport is also planned along the Outer Ring Road up to Kempapura station, then along NH-44 up to Doddajala station. From there, it moves parallel to an existing railway line for a short distance and then finally continues along the airport road median. The land required to construct the viaduct pier is available for almost the full length of the corridor. As the metro track follows a fairly flat road profile for this line, there would also be no steep gradients in the alignment. A vertical clearance of 5.50 m above road level is also proposed for the viaduct structures.

24. The proposed metro projects are expected to increase the share of public transport in total intracity passenger movements. It is expected to reduce carbon dioxide emissions and resultant pollution, thus improving the air quality in the city by shifting 0.46 million daily passengers from road to rail-based modes. The project is also expected to assist in orderly densification of the city instead of lateral growth of the urban area.

III. CLIMATE RISK AND VULNERABILITY ASSESSMENT

A. Rationale

25. Today, scientific evidence shows that the warming of the global climate system is unambiguous; global average temperatures are higher than they were in past centuries and continue to increase. As a result, seas and oceans are warming, polar ice caps and high elevation glaciers in mountainous regions are melting, sea levels are rising, and there are more varied and extreme weather patterns. According to the Intergovernmental Panel on Climate Change (IPCC), temperatures will be higher on average, there will be more incidents of record hot weather, precipitation levels and flooding risks will be higher, and more frequent and more severe extreme weather events are projected to increase under a changed future climate.

26. Since 2010, ADB has defined its priorities for action that include assisting developing member countries in climate-proofing of projects to ensure their outcomes are not compromised by climate change and variability or by natural hazards in general. Today, climate-related disasters such as floods, storms, droughts, and heat waves are on the rise worldwide. In the long run, climate change is bound to produce more severe hazards and threats to infrastructure. Therefore, tackling climate change impacts involves strengthening and/or improving upon already known deficiencies and building resilience to looming changes due to a warming planet.

27. A climate risk management approach has been adopted by ADB in an increasingly significant number of investment projects recognizing that development is about lasting benefits. A CRVA is mandated to be undertaken during the project preparation phase to examine climate change events and risks and, where appropriate, the technical and economic feasibility of adaptation measures. Based on the level of climate change risks for the project and the adaptation measures incorporated in the project design, the associated climate change adaptation costs are determined. In essence, the CRVA is a collaborative process aimed at informing project teams and stakeholders about future climate risks that can affect the performance of an investment project.

28. ADB has institutionalized a framework[6] in response to the mandated requirement that exposure and vulnerability to climate change risks be identified and accounted for in the preparation of investment projects. The framework encourages a sequential process to assess climate change vulnerability and impacts, and to identify adaptation needs and options.

B. Scope, Methodology, and Limitations

1. Scope

29. The broad objectives of this CRVA are to (i) assess the exposure, sensitivity, and adaptive capacity of the investment project to climate risks; and (ii) examine climate-risk adaptive interventions to build resilience. The scope of this report thus lies in the assessment of climate-related natural hazards and associated risks and vulnerabilities of Phase 2A and Phase 2B of the Bengaluru metro rail system. This report will deal in part as brief narrative descriptions with regard to objective (i), while the main focus of the CRVA is in dealing with objective (ii) which is to narrow down the deliberations to climate change adaptive measures planned for the project as reflected in the final DPRs and to disclose their associated incremental costs, if any.

2. Methodology

30. **Desk reviews.** Climate change studies are ongoing exercises being undertaken by various research institutes, governments, as well as nongovernment bodies. Desk reviews draw attention to many of the issues in vulnerability assessment and adaptation related to transport infrastructure where others have already explored those questions.

31. This report draws upon previous studies through literature search of materials that analyze what the far-reaching impacts on climate change might mean for the investment project in the rail sector. The desk resources include the DPRs for Phase 2A and Phase 2B provided by the BMRCL.

32. **Consultations with stakeholders and experts.** Broad-based representative consultation help ensure a wide range of perspectives on climate change and vulnerabilities. The key stakeholder, i.e., the BMRCL in this project, usually possess first-hand knowledge about the extent to which climate stressors affect or can affect the project. Experts can provide substantive information on the identification and analysis of vulnerabilities while engineers will be able to provide information or analysis related to sensitivity, including design and construction standards relevant to climate impacts and adaptive capacity information.

3. Limitations

33. Climate factors manifest their effects in a multitude of ways that make climate proofing a challenging activity given the complexities and uncertainties of the factors that define climate risks and vulnerability, particularly at the project level. Although the impacts of climate change are widely recognized, there exist gaps in guidance materials and information resources necessary to facilitate the climate proofing of investment projects within the region. Furthermore, there is no clear and universally adopted methodology to model the adverse effects of climate change and its integration in infrastructure design procedures. As such, there will certainly be a large number of important qualification and limitation issues in relation to the presentation of this vulnerability assessment and the application of adaptation strategies.

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[6] ADB. 2014. Climate Proofing ADB Investment in the Transport Sector, Initial Experience. Manila.

34. The sequential process recommended in the ADB framework to assess climate change vulnerability and impacts and to identify adaptation needs and options could not be strictly followed for projects where advance actions have been done by the executing agency. In the case of Bengaluru Metro projects, the detailed designs (DPRs) are already finalized prior to the detailed CRVA, leaving the recourse to study the DPRs for climate change adaptive measures incorporated in the project and disclose those measures here in this report. Still, it is important to note that the BMRCL has a good awareness of climate change impacts and is open to adopting mitigation measures to minimize these in the project.

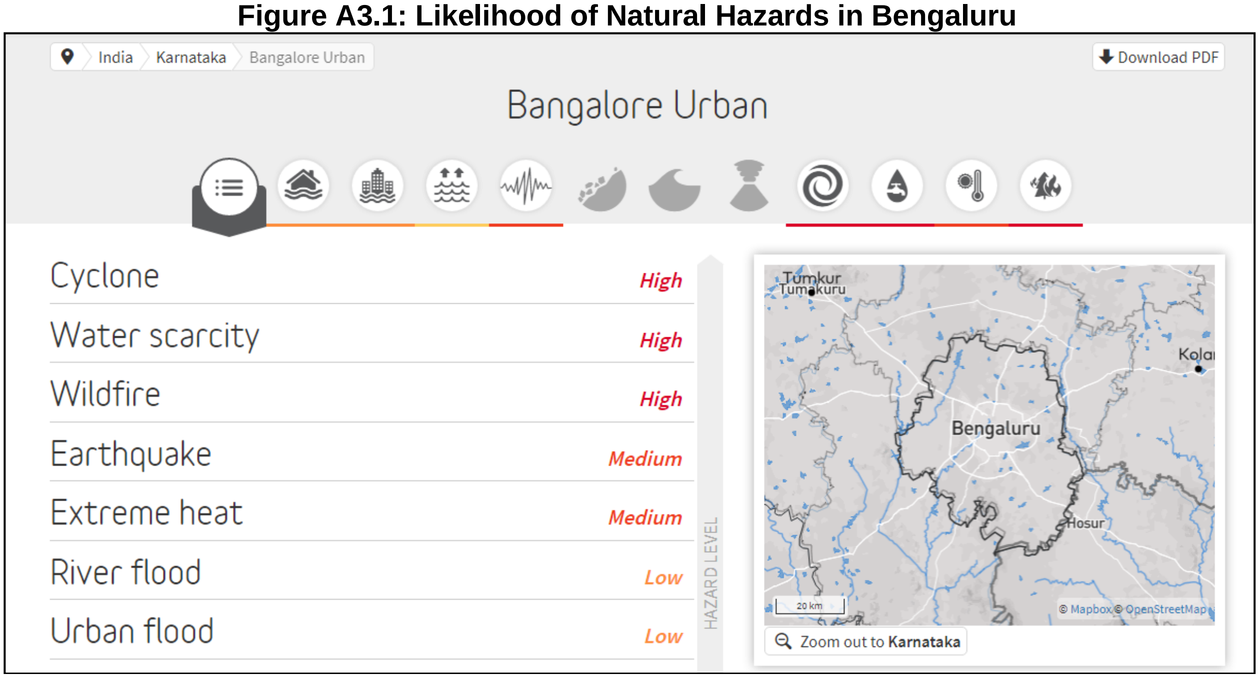
IV. NATURAL HAZARDS AND RISKS IN BENGALURU

A. Likelihood of Natural Hazards

35. A general perspective of natural hazards and risks in Bengaluru are derived from a web-based tool, ThinkHazard.[7] ThinkHazard is a simple and quick yet robust analytical tool that enables development specialists to determine for a given project location the potential likelihood of 11 natural hazards, and what actions they should take to make their project resilient. The tool analyzes hazard under current climate conditions and also provides guidance from IPCC on how climate change may alter hazard frequency and intensity into the future.

36. By using the tool and applying it specifically to Bengaluru, the likelihood of natural hazards such as cyclones, water scarcity, earthquake, extreme heat, river flood, and urban flood is identified with risk levels categorized as very low, low, medium, and high. The screenshot shown in Figure A3.1 is reproduced from the ThinkHazard webpage for Bengaluru Urban. The hazard levels provided in this tool are reportedly based on published hazard data, provided by a range of private, academic, and public organizations.

Figure A3.1: Likelihood of Natural Hazards in Bengaluru



Source: ThinkHazard.

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[7] ThinkHazard was developed for informational purposes by the Global Facility for Disaster Reduction and Recovery. http://thinkhazard.org/en.

37. ThinkHazard web-tool outputs are not project-specific. Thus, further detailed information is recommended to be obtained to adequately account for the level of hazard in the project area. Nevertheless, based on information currently available, ThinkHazard provides the following hazard accounts and recommendations that could be followed in different phases of the project to help reduce the risks to the project:

(i) **Cyclone.** Cyclone (also known as hurricane or typhoon) hazard is classified *high* and this means that there is more than a 20% chance of potentially damaging wind speeds in the project area in the next 10 years. Based on this information, the impact of cyclones must be considered in all phases of the project, particularly during design and construction.

(ii) **Water scarcity.** Water scarcity is classified *high* and this means that droughts are expected to occur on average every 5 years. Based on this information, the impact of drought must be considered in all phases of the project, particularly its effect on personnel and stakeholders, and during the design of buildings and infrastructure. Further detailed information should be obtained to adequately account for the level of hazard.

(iii) **Earthquake.** Earthquake hazard is classified *medium* and this means that there is a 10% chance of potentially damaging earthquake shaking the project area in the next 50 years. Based on this information, the impact of earthquake should be considered in all phases of the project, particularly during design and construction. Project planning decisions, project design, and construction methods should take into account the level of earthquake hazard.

(iv) **Extreme heat.** Extreme heat hazard is classified *medium* based on modeled heat information and this means that there is more than a 25% chance that at least one period of prolonged exposure to extreme heat, resulting in heat stress, will occur in the next 5 years. Project planning decisions, project design, and construction methods should take into account the level of extreme hazard.

(v) **River flood.** River flood hazard is classified *low* based on modeled flood information currently available and this means that there is a more than 10% chance that potentially damaging and life-threatening river floods will occur in the coming 10 years. Project planning decisions, project design, and construction methods should take into account the level of river flood hazard. Surface flood hazard in urban and rural areas is not included in this hazard classification and may also be possible in the project location.

(vi) **Urban flood.** Urban flood hazard is classified *low* based on modeled flood information currently available and this means that there is a more than 10% chance that potentially damaging and life-threatening urban floods will occur in the coming 10 years. Project planning decisions, project design, and construction methods should take into account the level of urban flood hazard.

38. Remarks on above:

(i) **River and urban floods.** Model projections for river and urban floods are inconsistent in their estimates of changes in rainfall. The present hazard level depicted in Figure A3.1 may increase in the future due to the effects of climate

change. It would be prudent to design projects in this area to be robust to river flood hazard in the long term.

(ii) **Cyclones.**[8] Global average tropical cyclone wind speed and rainfall are likely to increase in the future, and the global average frequency of tropical cyclones is likely to decrease or remain unchanged. It is possible that the frequency of the most intense tropical cyclones will increase substantially in some ocean regions. The present hazard level in areas currently affected by tropical cyclones may increase in the long term. Projects located in such areas should be robust to future increases in cyclone hazard.

(iii) Note that cyclone wind risks cannot be totally mitigated, and damages are not limited to wind but also to cyclone-induced heavy rainfall and subsequent flooding.

B. Urban Flooding

39. A vulnerability assessment of flood-affected areas of Bengaluru[9] states that the first recorded incident of urban flooding in the city occurred a little more than a century ago, when on 18 September 1912, the central business district around Fort Area of the city was affected by flood resulting from a bout of intense rainfall. Flood waters entered into buildings, leaving people stranded in knee-deep water. The overflowing drains inundated roads and low-lying areas of the city, which took 6 days to recede. The municipality then deemed the entire storm water drain infrastructure inadequate.

40. Now a century later, monsoon rains continue to plague Bengaluru city almost annually in the absence of an integrated approach in mitigating urban floods by the city's administrative body, the Bruhat Bengaluru Mahanagara Palike. In the name of development and demand for land, low-lying flood plains as well as the city's numerous lakes are transformed for urban infrastructure with previous lessons unaccounted. The conversion of natural land to impervious surfaces has resulted in faster rainfall–runoff processes and reduced recharge. Negative impacts of rapid urbanization and unplanned infrastructure development such as dumping of solid waste, laying of cables in the channels, and under-capacity stormwater drains and culverts have all added to urban flooding woes.

41. According to the National Disaster Management Authority's Guidelines on Management of Urban Flooding,[10] problems associated with urban floods range from relatively localized incidents to major incidents, resulting in cities being inundated from a few hours to several days. The guideline states:

> "Urban flooding is significantly different from rural flooding as urbanisation leads to developed catchments which increases the flood peaks from 1.8 to 8 times and flood volumes by up to 6 times. Stormwater drainage systems in the past were designed for rainfall intensity of 12–20 mm. These capacities have been getting very easily overwhelmed whenever rainfall of higher intensity has been experienced. Further, the systems very often do not work to the designed capacities because of very poor

[8] Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Summary for Policymakers, Technical Summary and Frequently Asked Questions.

[9] R. Prasad and Narayanan, P. 2016. Vulnerability Assessment of Flood Affected Locations of Bangalore by Using Multi-Criteria Evaluation. School of Earth Science, Central University of Karnataka. March.

[10] Government of India, National Disaster Management Authority (DMA). 2010. National Disaster Management Guidelines, Management of Urban Flooding, NDMA. September.

maintenance."

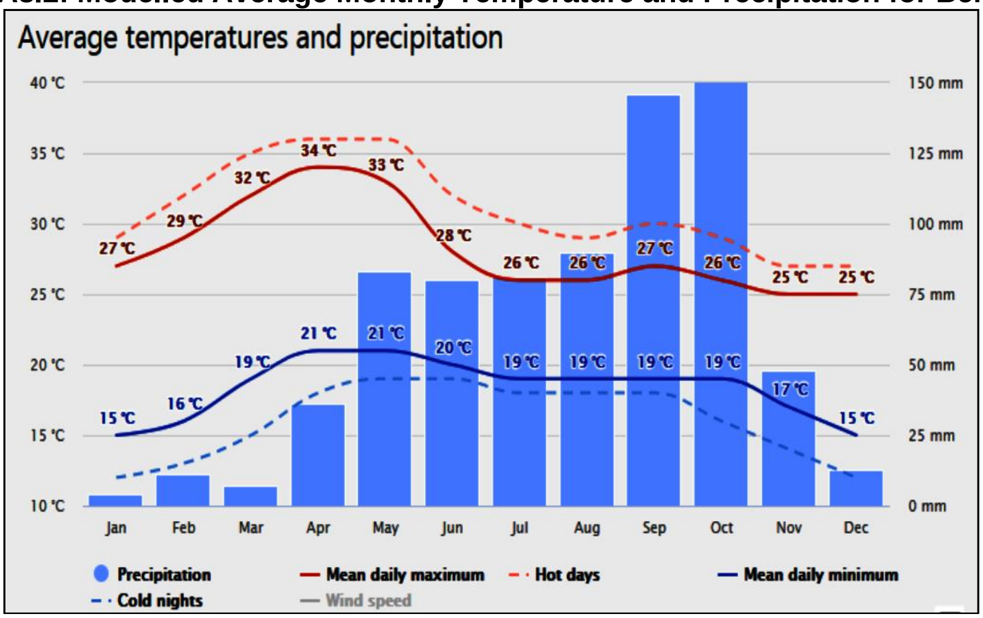
V. CLIMATE, OBSERVED TRENDS, AND CLIMATE CHANGE

A. The Baseline Climate of Bengaluru

42. Meteoblue.Data.org offers climate information on its website[11] and the Meteoblue climate diagrams presented below are based on over 30 years (from 1985 onwards) of weather data followed by weather model simulations. They give good indications of typical climate patterns and expected conditions in terms of temperature, precipitation, sunshine, and wind. The simulated weather data have a spatial resolution of approximately 30 km and do not reproduce all local weather effects, such as thunderstorms, local winds, or cyclones.

43. Figure A3.2 illustrates average monthly baseline information in terms of two important climatic variables, temperature and precipitation for Bengaluru (12.97°N 77.59°E, 920 m asl). The mean daily maximum (solid red line) shows the maximum temperature of an average day for every month in Bengaluru. Likewise, the mean daily minimum (solid blue line) shows the average minimum temperature. Hot days and cold nights (dashed red and blue lines) show the average of the hottest day and coldest night of each month during the last few decades.

Figure A3.2: Modelled Average Monthly Temperature and Precipitation for Bengaluru



Source: Meteoblue.Data.org.

B. Observed Climate Trends in Bengaluru

44. The Indian Meteorological Department (IMD) maintains a nationwide network of meteorological stations and provides climatic observations and products to national as well as international agencies such as the United Nations Framework Convention on Climate Change and the IPCC. The information in the following paragraphs on observed climate trends in Karnataka state is sourced from an IMD publication entitled State Level Climate Change Trends in India and is derived from long-term, observed datasets (1951–2010) from 282 stations for

[11] Meteoblue.com. Climate Bengaluru.

temperature and 1,451 stations for rainfall series across the nation.[12] The publication is meant to provide insight into climate change occurring over smaller regions and to assist the states in formulating their adaptation and mitigation strategies in light of rapidly changing climate trends.

1. Temperature Trends

45. State-level annual and seasonal mean maximum temperature, mean minimum temperature, and mean trends based upon 242 surface meteorological observations (20 for temperature and 222 for rainfall) in Karnataka for the observed period 1951–2010 are extracted in Table A3.2 below.

Table A3.2: Observed Temperature Trends in Karnataka State, 1951–2010

	Annual	Winter	Summer	Monsoon	Post-Monsoon
Mean maximum temperature trend in ºC per year	+0.02*	+0.02*	+0.02*	+0.02*	+0.02*
Mean minimum temperature trend in ºC per year	No trend	-0.01	-0.01*	No trend	No trend
Mean temperature trend in ºC per year	+0.01*	+0.01	No trend	+0.01*	+0.01*
Mean diurnal temperature range trend in ºC per year	+0.02*	+0.03*	+0.02*	+0.02*	+0.02*

Note: Increasing trend is indicated by a (+) and decreasing trend by a (-) sign. The asterisk (*) indicates significant trend at 95% confidence level.
Source: Indian Meteorological Department.

2. Rainfall Trends

46. Karnataka's annual rainfall is 1,151 mm on average. Around 80% of rainfall is received during the southwest monsoon, 12% in the post-monsoon period, 7% during summer, and 1% in winter. Within the state, there are considerable variations. During the southwest monsoon, rainfall is much higher in coastal locations on the windward side of the Western Ghats (3,350 mm) which drops sharply on the leeward side (600 mm–700 mm). Northern interior regions by contrast have markedly semi-arid climates with low annual precipitation (500 mm–600 mm).

47. The state-level annual and seasonal rainfall trends based upon 220 rainfall stations in Karnataka for an observed period 1951–2010 are reproduced in Table A3.3.

Table A3.3: Observed Rainfall Trends in Karnataka State, 1951–2010
(mm/year)

	Annual	Winter	Summer	Monsoon	Post-Monsoon
Annual and Seasonal Rainfall Trends	-0.05	+0.10	-0.41	+0.61	+0.14

mm = millimeter.
Note: Increasing trend is indicated by a (+) and decreasing trend by a (-) sign. The asterisk (*) indicates significant trend at 95% confidence level.
Source: Indian Meteorological Department.

48. A 2011 report submitted by the BCCI-K assessed trends based on daily weather data from

[12] Government of India. 2013. State Level Climate Change Trends in India; IMD Monogram No: ESSO/IMD/EMRC/02/2013.

the Indian Meteorology Department, Pune for the period 1901 to 2008.[13] The study observed a decline in total annual rainfall for the state: from 1,204 mm during 1901–1950 to 1,140 during 1951–2008. However, as shown in Table A3.4, both annual rainfall as well as seasonal rainfall increased for Bengaluru Urban.

Table A3.4: Normal Rainfall and Trends in Bengaluru Urban, 1901–2008

District	Pre-Monsoon (Jan–May)			Southwest Monsoon (Jun–Sep)			Northeast Monsoon (Oct–Dec)			Annual	
	Trend	mm	%	Trend	mm	%	Trend	mm	%	Trend	mm
Bengaluru Urban	↑	168	19	↑	466	53	↑	241	28	↑	875

mm = millimeter.
Source: Bengaluru Climate Change Initiative-Karnataka.

3. Extremes of Temperature and Precipitation

49. From a historical perspective, the ever-recorded maximum temperature, minimum temperature, and 24-hour heaviest rainfall up to year 2010 for two meteorological stations in Bengaluru are shown in Table A3.5 below.[14] Dates of occurrence of extremes are also shown.

Table A3.5: Ever-Recorded Maximum and Minimum Temperatures and 24-hour Heaviest Rainfall until 2010

Station Name and Number	Highest Maximum Temperature ºC (mm)	Lowest Minimum Temperature ºC (mm)	24-hour Heaviest Rainfall (mm)
Bengaluru Station No: 43295	38.9 (22 May 1931)	7.8 (13 January 1884)	178.9 (01 October 1997)
Bengaluru Station No: 43296	38.3 (14 April 1960)	8.8 (03 January 1993)	169.2 (07 October 1953)

mm = millimeter.
Source: Indian Meteorological Department.

C. Future Climate Projections

1. Temperature

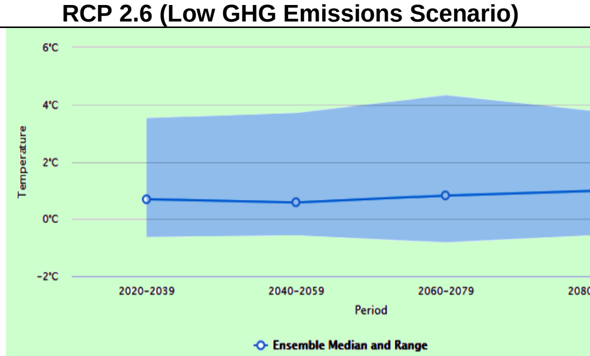
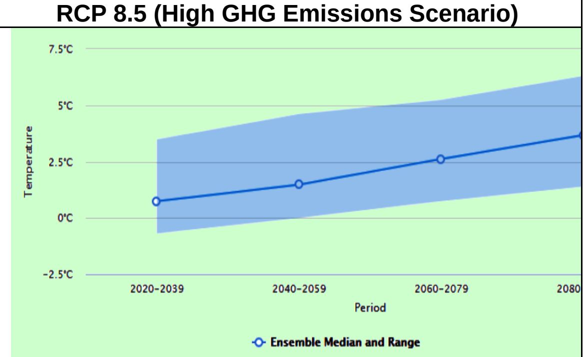
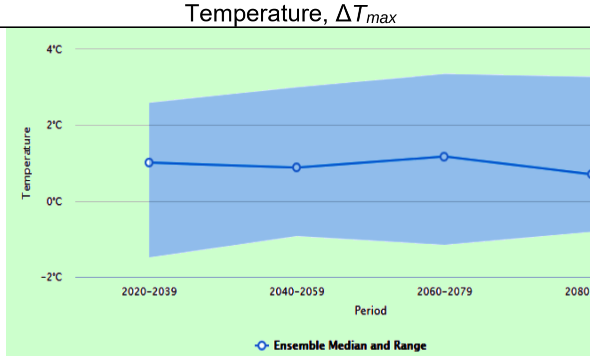
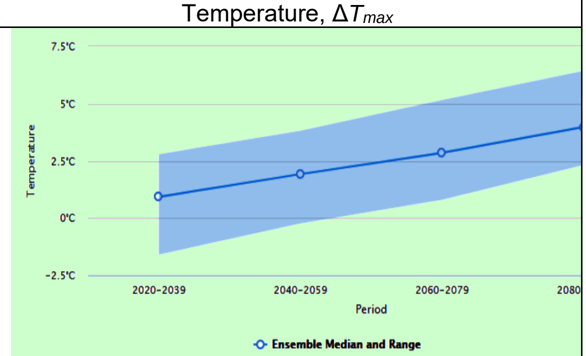
50. The World Bank's Climate Change Knowledge Portal[15] (CCKP) sources a suite of global climate models to help decision makers understand the projections of future climate change and related impacts. The CCKP supports the analysis of climate impacts using multi-model ensembles, as they represent the range and distribution of the most plausible projected outcomes when representing expected changes. Future climate information in the CCKP are derived from 35 available global circulation models used by the IPCC Fifth Assessment Report (AR5). The CCKP takes advantage of the most widely used Coupled Model Intercomparison Project, Phase 5 (CMIP5) model, with data presented at a 1°x1° global grid spacing and provides options to visualize climate variables and indices for different timeframes, statistics, emission scenarios, and climate models.

51. For land transport infrastructure, temperature extremes and their diurnal ranges are

[13] World Bank. Final Report submitted by Bangalore Climate Change Initiative – Karnataka (BCCI-K); A Project funded by World Bank.
[14] Indian Meteorological Department, Pune. Ever Recorded Extremes up to 2010.
[15] World Bank Group. Climate Change Knowledge Portal. India Climate Data Projections.

important variables in the design of various civil elements rather than average temperatures. For Bengaluru located at around 77.59°E, 12.97°N, the projected changes (anomalies) in daily maximum temperature (T_{max}) and daily minimum temperature (T_{min}) over the period of interest and relative to the reference period (1986–2005) are illustrated in Figure A3.3. The charts show the contrast in temperature anomalies estimated under lower and upper representative concentration pathways,[16] RCP2.6 and RCP8.5, respectively.

Figure A3.3: Projected Changes in Temperature for Various Timeframes (Location: 77.59°E, 12.97°N)

	RCP 2.6 (Low GHG Emissions Scenario)	RCP 8.5 (High GHG Emissions Scenario)
Daily Maximum Temperature, °C	 (A) Projected Change in Maxima of Daily Maximum Temperature, ΔT_{max}	 (B) Projected Change in Maxima of Daily Maximum Temperature, ΔT_{max}
Daily Minimum Temperature, °C	 (C) Projected Change in Minima of Daily Minimum Temperature, ΔT_{min}	 (D) Projected Change in Minima of Daily Minimum Temperature, ΔT_{min}

GHG = greenhouse gas, RCP = representative concentration pathway, T_{max} = daily maximum temperature, T_{min} = daily minimum temperature.
Source: World Bank's Climate Change Knowledge Portal.

52. The climate change projections for Karnataka state as given in the Karnataka Climate Change Action Plan is reported as adopted from the BCCI-K report that studied Karnataka's climate trends and made projections based on a coupled atmosphere–ocean general circulation model, HadCM3. Climate change projections for daily values of temperature (mean, maximum, and minimum) and daily values of precipitation were derived at grid-spacing of 0.44250 latitude by 0.44250 longitude and for SRES A1B midterm (2021–2050) emissions scenario relative to the baseline period 1961–1990. The SRES A1 greenhouse gas scenario formulated by IPCC's Special Report on Emission Scenarios (2000) stands for rapid economic growth in a globalizing world with balanced emphasis on all energy sources. The following Tables A3.5 and A3.6 show the midterm (2021–2050) projections of temperature and precipitation for the districts of

[16] Representative Concentration Pathway, a GHG concentration trajectory adopted by the IPCC. Four pathways are used for climate modeling and research since 2014: RCP2.6, RCP4.5, RCP6, and RCP8.5, labelled after a possible range of radiative forcing values in 2100 (2.6, 4.5, 6, and 8.5 watt per square meter, respectively).

Bengaluru Urban and Bengaluru Rural.

Table A3.6: Projected Increase in Mean, Maximum, and Minimum Temperatures, 2021–2050

No.	Districts	Projected Increase in Mean Temperature, T_{av},°C	Projected Increase in Mean Maximum Temperature, T_{max},°C	Projected Increase in Mean Minimum Temperature, T_{min}, °C
1	Bengaluru Urban	1.96	2.06	1.88
2	Bengaluru Rural	1.97	2.06	1.91

T_{max} = mean maximum temperature, T_{min} = mean minimum temperature, T_{av} = mean temperature.
Source: Karnataka Climate Change Action Plan.

2. Heat Wave

53. It is expected that extreme heat waves will become more common worldwide because of rising average global temperature. In Table A3.6, the mean maximum temperature in Bengaluru is projected to increase by around 2.06°C in the 2030s, which means the extreme upper temperature is also progressively pushed up. A 2016 publication by the National Disaster Management Authority of India reported an increasing trend of heatwave in India over the past several years whereby several cities in India have been severely affected.[17] Abnormally high temperatures were observed during April–June (pre-monsoon) 2010 to 2015 across the country.

54. In 2015, daily maximum temperature exceeded the average maximum temperature by more than 6°C to 8°C in many parts of India, and in Karnataka state, a highest maximum temperature of 44.1°C was recorded on 30 May 2015 at Kalburgi where the mean daily maximum temperature hovers usually at around 32.4°C.

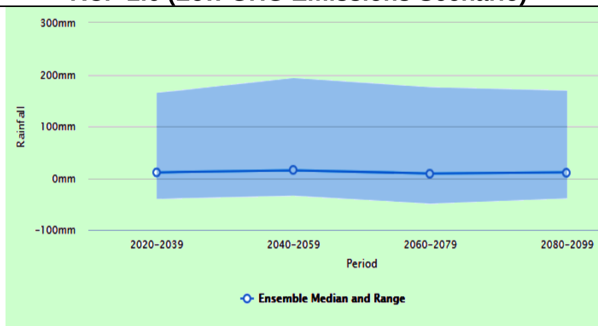
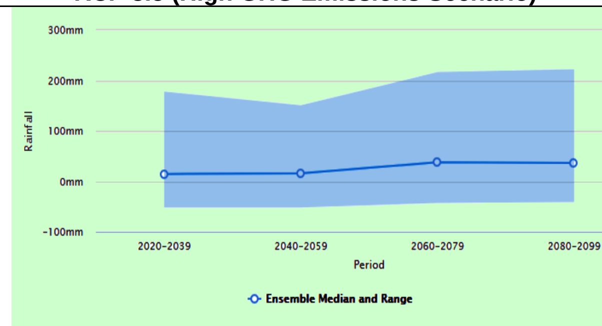
3. Rainfall

55. A common way to analyze changes in extreme precipitation is to follow the evolution of the percentiles of the daily precipitation. But in engineering design application, the magnitude of daily maximum rainfall or return level, and the associated frequency of extreme rainfall event or return period, are imperative.

56. The World Bank's CCKP as mentioned earlier provides CMIP5 projections of changes in maximum daily rainfall for return periods of 10 and 25 years. The projected rainfall changes for 25-year return periods under lower RCP 2.6 and upper RCP 8.5 scenarios are illustrated in Figure A3.4. A 25-year return level of daily precipitation is the maximum daily rainfall that can be expected once in an average 25-year (i.e., 4% chance) period with the possibility that two or more events of that magnitude can occur in much shorter intervals.

[17] National Disaster Management Authority. 2016. Guidelines for Preparation of Action Plan – Prevention and Management of Heat-Wave.

Figure A3.4: Projected Change in 25-year Return Level of Maximum Daily Precipitation (mm) (Location: 77.59°E, 12.97°N)

RCP 2.6 (Low GHG Emissions Scenario)	RCP 8.5 (High GHG Emissions Scenario)
	
(A) Projected Change in Annual Maximum Daily Precipitation, (25 yr Return Level)	(B) Projected Change in Annual Maximum Daily Precipitation, (25 yr Return Level)

GHG = greenhouse gas, RCP = representative concentration pathway.
Source: World Bank's Climate Change Knowledge Portal.

57. The climate change projections for mean change in annual and seasonal precipitation compared to the reference period (1961–1990) for Bengaluru Urban and Bengaluru Rural as given in the Karnataka Climate Change Action Plan is shown in Table A3.7. In general, the value of seasonal precipitation change varies between -15% and +36%.

Table A3.7: Projected Change in Annual and Seasonal Rainfalls, 2021–2050 (SRES A1B Emissions Scenario)

No.	Districts	Projected Change for JF Months (%)	Projected Change for MAM Months (%)	Projected Change for JJAS Months (%)	Projected Change for OND Months (%)	Projected Change in Annual Mean (%)
1	Bengaluru Urban	-15.11	29.92	-2.89	10.14	3.66
2	Bengaluru Rural	3.05	36.30	-2.31	9.61	3.56

JF = January/February, JJAS = June/July/August/September, MAM = March/April/May, OND = October/November/December.
Source: Karnataka Climate Change Action Plan.

VI. EXPOSURE, SENSITIVITY, AND RISK APPRAISAL

A. General

58. Two major types of climate-related risks to surface transport infrastructure, be it rail or road, are those driven by long-term changes in temperature and precipitation. The impacts driven by changing weather conditions possess the potential to accelerate deterioration, severe damages and risks, traffic interruption, and accidents, which eventually can disrupt economic activities. As such, there is today a growing number of reports and analyses done by government organizations, international agencies, and research faculties that (i) draw attention to the impact of climate change on transport infrastructure integrity and performance, and (ii) recommend that appropriate adaptation measures be undertaken.

59. Climate vulnerability has been traditionally understood in terms of a relationship between exposure, sensitivity, and adaptive capacity. Climate change vulnerability levels are influenced by variables such as geographic location, the local environment, and the ability of local authorities to both respond to events and adapt their assets in advance.

60. Due to direct exposure to forces of nature, rail infrastructures and operations are vulnerable to many different types of weather conditions. These forces of nature are highly likely to be exacerbated under climate change. Generic impacts of climate change on rail infrastructures/assets as identified in numerous literatures are briefly outlined here. These impacts call for careful consideration of rail design, construction, and maintenance to achieve lasting benefits.

(i) Rise in air temperature and temperature extremes can accelerate buckling of rail tracks. It should be noted that under direct sunlight, tracks can get as high as 20ºC hotter than the ambient air.
(ii) Rise in air temperature and temperature extremes can cause overhead electrical lines to expand and sag in heat with the danger of touching the tops of train carriages.
(iii) Rise in temperature extremes impacts on concrete construction practices, including thermal expansion affecting rail bridge and elevated viaduct expansion joints.
(iv) Changes in rainfall, temperature, and evaporation patterns can alter the moisture balances in rail track bed foundations and formations.
(v) Rise in the water table can lead to the reduction of the structural strength of the formations, leading to damages to earthworks, embankments, and drainage systems.
(vi) Precipitation increase and increase in intense precipitation events can cause overloading of drainage systems, causing backups, flooding, and track formation washouts. It should be noted that in the case of heavy rains when the city's roads and rails get flooded, all at-grade systems and underground systems can get severely affected despite all necessary precautions.
(vii) Changes in seasonal precipitation and river flow patterns induce increased risk of floods from runoff, landslides, slope failures, and damage to rail track formation and bridges.
(viii) Storms and more frequent strong cyclones can bring about increased flooding, greater probability of infrastructure failures, erosion of rail track foundation and bridge supports, bridge scour, reduced clearance under bridges, wind damage to roofs of stations, lighting, overhead cables, rail signals, and other tall structures.

B. Sector Climate Risk and Vulnerability of Bengaluru Metro Projects

61. According to a 2017 Technical Report done by the Indian Institute of Science, Bengaluru is experiencing unprecedented urbanization and sprawl in recent times due to concentrated developmental activities with impetus on industrialization for the economic development of the region. This concentrated growth has resulted in the increase in population and consequent pressure on infrastructure and natural resources, and ultimately raising serious challenges such as climate change impacts, enhanced greenhouse gas emissions, lack of appropriate infrastructure, traffic congestion, and lack of basic amenities (electricity, water, and sanitation) in many localities of the city.[18]

62. The report shows that there has been a growth of 1,028% in urban areas of Greater Bengaluru across 45 years (1973 to 2017). Urban heat island phenomenon is evident from large number of localities with higher local temperatures. The study unravels the pattern of growth in

[18] Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science. 2017. Frequent Floods in Bangalore: Causes and Remedial Measures. Bangalore, Karnataka. August.

Greater Bengaluru and its implication on local climate (an increase of around 2ºC to 2.5ºC during the last decade) and also on the natural resources (88% decline in vegetation cover and 79% decline in water bodies), necessitating appropriate strategies for sustainable management.

63. This report underscores the consequence of increased impermeable catchments resulting in higher catchment yield in much shorter duration with flood peaks sometimes reaching to as high as 3 times beyond normal. Thus, flooding occurs in a matter of minutes. Causal factors include (i) combinations of loss of pervious area in urbanizing landscapes; (ii) inadequate drainage systems; (iii) blockade due to indiscriminate disposal of solid waste and building debris; (iv) encroachment of storm water drains; (v) loss of interconnectivity among lakes, housing in floodplains, and natural drainage; and (vi) loss of natural flood-storage sites.

64. The Bengaluru metro rail project is a complex undertaking comprising many different interacting infrastructures including earthworks and civil structures, rapid rail track structure, signaling, and many interconnected installations. The preceding sections underline the available information on climate hazards and vulnerabilities of the project location based on several sources of information. As rail infrastructures are sensitive to increasing and critical risk from climate-driven stressors, the following paragraphs look at the project risks by identifying significant long-term impacts that may develop slowly, and also immediate concerns about the impacts from extreme weather events that have occurred recently and may reoccur.

65. Significant risks to the project are posed by both ambient and periodic extremes in temperature, consecutive days of extreme heat (heat waves), extreme precipitation, and impacts by flooding.

66. Risks due to extreme temperature:

(i) Earlier in section V, Table A3.6 on climate change projections for 2021–2050 under A1B scenario as well as the World Bank's CCKP under RCP 2.6 and RCP 8.5 scenarios showed the annual average temperature, and the minimum, maximum, and monthly mean temperatures for Bengaluru Urban to be on the increasing side. This increase in average temperature translates to increase in extreme hot weather conditions.

(ii) The proposed Phase 2A line from Central Silk Board junction to K.R. Puram and Phase 2B line from K.R. Puram to Kempegowda International Airport are designed as elevated metro with track supporting structures with a vertical clearance of 5.50 m above road level. Due to direct exposure to sunlight, rail infrastructures and operations are vulnerable to extreme temperature conditions with thermal impacts highly likely to be exacerbated under climate change.

(iii) The issue of temperature impact on rails is not a current phenomenon. The temperature of steel rails can reach some 20+ degrees higher than the air around them when exposed to direct sunlight. So, when ambient temperatures approach 38+^{o}C, which Bengaluru experiences during pre-monsoon (Table A3.5), rail track temperatures can shoot up to as high as or over 600^{o}C. That causes the metal to expand, putting it at risk of misalignment and deformations that are introduced in rail when the weight of train cars put stress in areas that are weakened by exposure to excessive heat.

(iv) The complicating factor of climate change for the rail network is that the frequency

and magnitude of extreme heat conditions is projected to increase, significantly in some instances, which increases the risk of failures due to track expansion. Currently, the accepted practice for addressing these heat events is to reduce the traffic on the affected areas by reducing the speed of the trains, or in extreme events, stopping traffic completely for a period of time.

(v) The elevated viaducts (or bridges) of reinforced cement concrete are exposed structures and during their lifetime will be subjected to daily, seasonal, and yearly repeated cycles of heating and cooling induced by solar radiation and surrounding air. Variation of temperatures affect concrete structures in a highly complicated manner as influenced by factors such as the rate of temperature rise and the aggregate type and stability. Movements of concrete structures due to expansion and contraction under temperature changes are accommodated by bearings and expansions joints but with pervasive changes induced by extreme heat may eventually lead to deformations and failure. Furthermore, abrupt temperature changes can cause cracking and spalling of concrete due to thermal shock, and aggregate expansion can also produce distress within the concrete.

67. Risks due to extreme rainfall

(i) Earlier in section V, Table A3.4 on normal rainfall and observed trends during the years 1901 to 2008 in the urban area of Bengaluru shows that the annual precipitation variability has increased. During 1901–2008, rainfall during the monsoon months (June–September) has gone up by 53% against a normal of 466 mm. In terms of future rainfall projections for the urban area of Bengaluru, section V, Table A3.7 on June–September total precipitation shows a minor downward trend by 2.89% for 2021–2050. Although the projection shows to be insignificant, it should be noted that under climate change, intense rainfall incidents are expected to be more frequent and more intense, leading to an increasing risk of flooding.

(ii) The 2017 Indian Institute of Science Technical Report states that frequent flooding (since 2000, even during normal rainfall) in Bengaluru is a consequence of the increase in impervious area with the high-density urban development in the catchment and loss of wetlands and vegetation. This is coupled with narrowing and concretizing storm water drains, lack of appropriate drainage maintenance works with the changes in enhanced run-offs, the encroachment and filling in the floodplain on the waterways, obstruction of sewer pipes and manholes and relevant structures, deposits of building materials and solid wastes, and flow restrictions from under-capacity road crossings (bridge and culverts).

(iii) The proposed Phase 2A line from Central Silk Board junction to K.R. Puram and Phase 2B line from K.R. Puram to Kempegowda International Airport are designed as mostly elevated metro systems. The projects do not incorporate underground tunnels and, as such, significant potential risk of flooding of tunnels by ingress of flood waters from various sources such as river (fluvial) flooding, surface water (pluvial) flooding, and burst city water pipes are not presented.

(iv) Increased volume, frequency, and intensity of precipitation under climate change can cause overloading of existing drainage systems, thus causing backups and flooding. Elevated concrete structures for Phase 2A and Phase 2B metros

envisaged to be constructed along road medians create expanses of impervious surfaces, thus promoting faster (efficient) transformation of rainfall to runoff, which adds on to already flooded roads below.

(v) The dynamics of flooding in various areas of Bengaluru are complicated yet it is emphasized that heavy rainfall is the primary cause of flooding in the city. Water may be considered the greatest enemy of transport infrastructure, and climate change is likely to drive an increase in storms and floods in the city. The immediate impact of floods in Bengaluru's transport system can be visualized by the boxed scenes given in Figure A3.5.[19]

(vi) With regard to risks by fluvial flooding in the city by the rivers Arkavathi and Vrishabhavathi that flow through Bengaluru, the current state of affairs is quite complicated. What used to flow as pristine rivers until the 1970s, the Arkavathi and Vrishabhavathi are now urban drains (Mori in Kannada) with pollutants from industries, and with the Bangalore Water Supply and Sewerage Board having connected all the sewer lines to the river. These rivers together carry much of Bengaluru's sewage.

(vii) An account of the flooding problem in the city states: "The Arkavathy and Vrishabhavathi rivers became sewage rivers, tanks dried up, other water bodies were breached, and tank bunds and catchments areas were encroached upon and construction allowed. Naturally, the water bodies became septic and the Vrishabhavathi became nothing more than a huge cesspool. … The Arkavathy and Vrishabhavathi rivers were interconnected to the many lakes and tanks of Bangalore from the time of Kempe Gowda. If one tank overflowed, the water would percolate to the other. Thus, there was no flooding till a few decades ago."[20]

Figure A3.5: Impact of Floods in Bengaluru's Transport System

Box 1	Box 2
	
Source: rainmanspeaks.blogspot.com.	Source: drivespark.com.

[19] Box 1: rainmanspeaks.blogspot.com (RainManSpeaks from Bangalore: From trickle to flood). Box 2: drivespark.com (Incessant monsoon rains flood Bangalore streets).

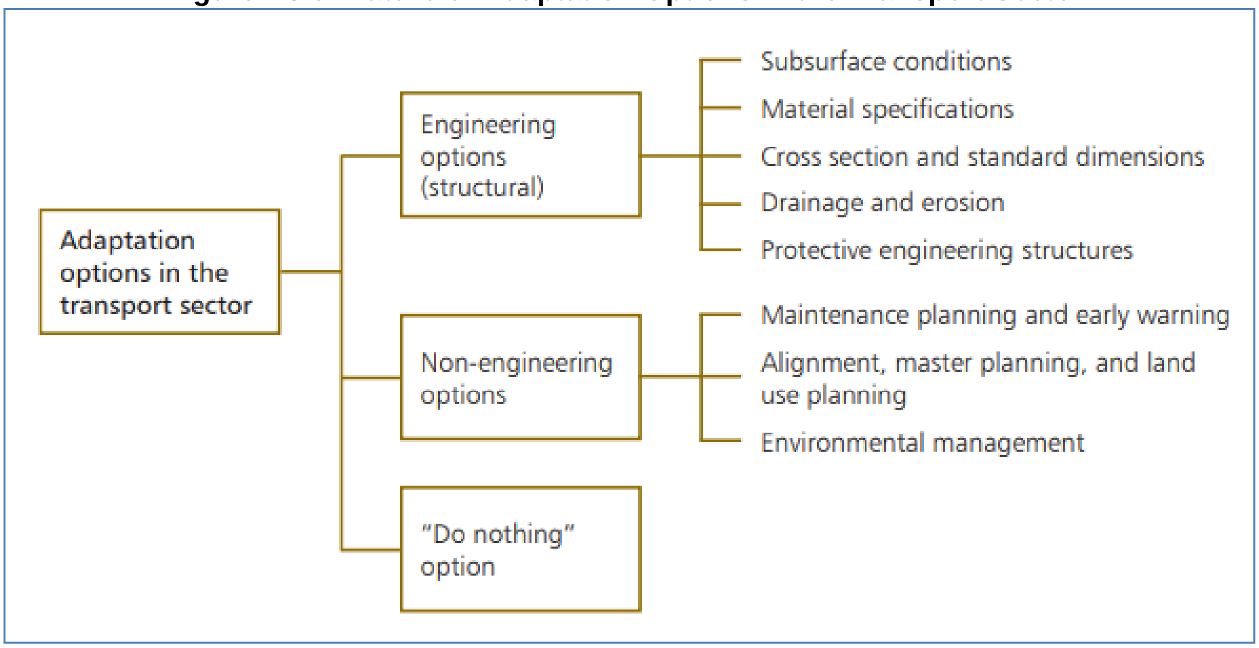
[20] Suttha Muttha. 2012. Namma Bangalore-Mysore: The cities that never cease to surprise. 16 November.

VII. ADAPTATION MEASURES IN THE BENGALURU METRO PROJECTS

A. General

66. According to ADB's Guidelines for Climate Proofing Investment in the Transport Sector, adaptation options in the transport sector may generally be grouped into engineering (structural) options and non-engineering options as shown in Figure A3.6. Adaptation options from the structural point of view look at design standards of vital project components that may be compromised by climate change, which include (i) subsurface materials, composition, stability, and strengths; (ii) material specifications in terms of physical properties and behavior under environmental severity; (iii) cross-sections and dimensions of project elements; (iv) drainage and erosion considerations responsive to changes in future rainfall and runoffs or floods; and (v) other protective engineering structures.

Figure A3.6: Nature of Adaptation Options in the Transport Sector



Source: Asian Development Bank. Guidelines for Climate Proofing Investment in the Transport Sector. 2014.

67. Non-engineering options of climate change adaptation for the project looks at various processes of adjusting to changing climate and its cascading impacts, which include (i) maintenance planning and early warning, (ii) master planning including land use planning, and (iii) local environmental management. Environmental management aspects are examined in the environmental safeguard assessments and documented in Chapter 14 on Environment and Social Impact Assessment (ESIA) of the DPRs for Phase 2A and Phase 2B, as well as the environmental impact assessment prepared in compliance with ADB requirements. The ESIA looks into effects of project activities on the immediate environment and environmental quality issues and recommends risk mitigation or adaptation measures to be considered during the project design and construction phases.

68. Being a relatively new area of discourse, decision-making in climate change adaptation measures can be difficult primarily due to information gaps, or because conclusions from the vulnerability, sensitivity, and impact assessments may be inconclusive. Here, the project design may justify retaining a business-as-usual (BAU) approach or "do nothing" option as indicated in

Figure A3.6. For such cases, adaptative maintenance or incremental adaptation actions can be decided and implemented in successive short timescales. This can provide advantage in managing climate change uncertainty iteratively, based on gradual, increasingly reliable climate change knowledge. This reduces the risks of committing to highly expensive initial investment. Also, not all adverse consequences of climate change on a project can be avoided through adaptation alone.

B. Review of the Detailed Project Reports

69. Section III B (iii) on limitations of this CRVA indicated that the ADB framework desires a sequential process beginning with an assessment of climate change vulnerabilities and impacts, followed by the identification of adaptation needs and options. The DPRs for the proposed Phase 2A and Phase 2B metro lines are already prepared, revised, and finalized during October 2019 by the BMRCL prior to carrying out this CRVA study. As the CRVA could not align in accordance with the preferred sequence described above, the recourse here is to (i) review the DPRs for any climate change adaptive measures incorporated in the metro design, and (ii) disclose those measures, if any, and their associated costs in this report.

70. The DPRs are said to have been finalized in compliance with the following guidelines and policies of the Government of India: (i) Metro Rail Policy 2017,[21] (ii) Draft Comprehensive Mobility Plan 2019 for Bengaluru City,[22] (iii) Draft Revised Master Plan 2031 for Bengaluru Region,[23] and (iv) various other studies undertaken for traffic and transportation for the city by the Government of Karnataka. Furthermore, the metro design is said to adhere to the latest standards and specifications issued by the Ministry of Housing and Urban Affairs for the development of the metro system in the identified corridor. Unfortunately, none of the policies and guidelines stated above make any mention of the need to take into account the risks and impacts by climate change in transport infrastructure planning and design.

71. Except for earthquake hazard where the metro design has been adopted to Indian Zone II seismicity as applicable to Bengaluru, the DPRs have not seen the need for an inclusive treatment of other climate-driven stresses whose impacts can impede normal operation and maintenance or can disrupt the city's transportation modes in future.

72. The finalized alignments for Phase 2A and Phase 2B have been decided on the basis of high ridership potential and the entire alignment is planned to be elevated, taking into account least land acquisition, geologic conditions along the route, and economic considerations. The elevated viaduct structures are to generally follow along and above the median of some of Bengaluru city's busiest roads. Metro stations are also proposed above the road with entries planned from both sides of the road beyond existing service roads.

73. The DPRs note that various design norms and parameters have been firmed up by the BMRCL after detailed studies of norms and parameters followed by metro systems in various cities. Certain modifications to the design norms have been made keeping in view technological advancements and specific needs of Bengaluru city. This would also imply that the BMRCL would have examined the experiences and lessons from similar projects in India concerning current weak spots under exposure to already known natural hazards that have impeded operation and

[21] Ministry of Housing and Urban Affairs. 2017. Metro Rail Policy.
[22] Open City Urban Data Portal. 2019. Bengaluru Comprehensive Mobility Plan (CMP) Draft – October and 18 December.
[23] Bangalore Development Authority. Revised Master Plan 2031 for Bengaluru Region.

maintenance of metro rail systems. It must be noted that many of the adaptations that deal with current operational problems help build resilience even if not specifically targeting climate change, although climate change might produce new kinds of hazards and threats in the future.

C. Climate Change Adaptation Measures Incorporated in the DPRs

74. The overall objective of the Bengaluru metro investment project is to achieve long-term serviceability and economic benefits. The core of adaptation to negative impacts of both climatic and non-climatic risks lies in the fact that all infrastructure components should at the outset be well constructed and founded on robust groundwork so that deterioration does not result from inadequacies in construction, and/or deficiencies in the structural properties, and/or quality of materials. This adaptation approach rests with the BMRCL and comprises setting and enforcing adequate engineering and performance standards during the construction phase.

75. A primary cost incurred by railways lies in the maintenance and renewal of track and its related infrastructure caused by temperature-induced defects such as buckling and kinks (areas of rail weakened by exposure to excessive heat) and rolling contact fatigue defects (RCF) as a result of intensive usage. Earlier, section VI B highlighted climate change projections for 2021–2050 under the A1B scenario as well as the World Bank's CCKP under RCP 2.6 and RCP 8.5 scenarios that showed the annual average temperature, and the minimum, maximum, and monthly mean temperatures for Bengaluru city to be on the increasing side. Risks to rail tracks due to extreme temperature are well-known as elevated metro rail tracks will be constantly exposed to elements of nature, including extreme high temperatures resulting from direct exposure to sunlight and variability in diurnal temperatures.

76. For rail tracks, the BMRCL has proposed the use of head-hardened 1080 steel rails (UIC60), a product of recent advances in special heat treatment of steel that achieves an increase in hardness by nearly 50% in comparison with standard steel grades. Technology improvements in track components can assure better track performance under severe climatic conditions and longer service lifetime, achieve high level of safety and efficiency, and are subjected to intensive usage with very little time for day-to-day maintenance.

77. Temperature impacts on rails include buckling or alignment deformation due to thermal stresses that build up in rails. The new tracks are proposed to be continuous welded rail, mechanically or thermally altered to achieve a measured length equivalent to a stress-free temperature before it is clipped down. This action ensures that at a known temperature (dependent on location), there would be no thermal forces, either compressive or contractive, in the rail. This stressing of rail installs a stress-free temperature so that there will be a greatly reduced risk of fracturing or buckling at temperature extremes. The design temperature for rails in Phase 2A and Phase 2B of the Bengaluru metro project is designed to take up a temperature range from -10^{o}C to 70^{o}C.

78. Although section VI B revealed changes in future rainfall projection (2021–2050) to be insignificant, an important point to note is that under climate change, rainfall incidents are expected to be more frequent and more intense, leading to an increasing risk of flooding. Rainfall is reported to be the primary cause of flooding in the city and the observed increase by 53% of June–September monsoon rains during 1901–2008 in Bengaluru (Table 4.3) is a significant trend indicating that Bengaluru will need to become more resilient to flooding when it does occur through prevention, preparation, and planning. The risk of flooding is recognized as one among many other disaster-causing factors and is addressed in the DPRs. Chapter 15 of the DPRs is dedicated to disaster management and security measures that include early warning systems, limiting

exposure to flooding and the damage it causes, and through organization of more effective recovery.

79. The elevated viaducts (or bridges) of reinforced cement concrete that run through the median of the city's busy roads are exposed impermeable structures that transform rainfall to runoff in much shorter duration and that add to water logging of the already flooded roads below. To alleviate this distress to some extent, means of water harvesting from elevated structures have been proposed in the design of Phase 2A and Phase 2B viaduct structures. The cross-slope or camber provided in the viaduct superstructure design permits runoffs to be channeled through drain piping to water harvest ponds, which are proposed to be constructed between each pier span where the accumulated water is settled to allow percolation into natural ground.

80. Where water accumulates for days due to an ineffective road drainage system, there are the risks of reduced bearing capacities of water-logged soils on which the pier foundations are set as elevated structures applying considerable load on the foundation system. Along the proposed metro corridor, hard rock strata are encountered within 4.5 m to 5 m depth below existing ground level, permitting the foundations to be positioned on hard strata. The possibility of occurrence of upward force by hydrostatic pressure on the foundation is also eliminated. In areas where hard rock stratum is encountered at considerable depths, the foundation supporting the elevated rail track and elevated stations are proposed to be supported on pile foundations based on geotechnical investigations. The end bearing piles are to be socketed into the hard strata, which could be soft weathered rock or hard rock.

D. Climate Change Adaptation Cost

81. Climate change risk assessment is dominated by uncertainty that can only be reduced with improved knowledge and information in the course of time. In this assessment and by the line of reasoning in the preceding sections on issues of climate change vulnerabilities, the Bengaluru metro project is assessed to be of *medium risk* in terms of anticipated impacts.

82. The design of the Bengaluru metro project is said to adhere to latest standards and specifications that feature improvements in technology, improved standards in construction methods, and use of better quality materials. The application of concrete mixes that are more durable, techniques such as elevating rails to cope with flooding, and use of thermally treated head-hardened steel rails against temperature stresses and wear and tear, are optimistic adaptation measures against adverse effects by climate change. Any upgrade in construction technology can enhance resilience to climate stresses and shocks. Thus, additional climate change adaptation inputs and costs are considered for the metro projects at this stage. It must be noted that whatever the level of technology, any further adaptation is likely to be an iterative process rather than a one-off activity.

83. The preceding section raised the issue of contribution of rainfall runoffs by the elevated viaducts to water logging of the already flooded city roads. As a mitigation measure, water harvesting from elevated structures and from rooftops of elevated stations has been proposed in the design of Phase 2A and Phase 2B metro lines. The total cost to this mitigation measure as shown in Table A3.8 is about INR84.6 million.

Table A3.8: Cost of Water Harvesting

Sl.No	Description	Unit	Qty	Rate	Amount	Remarks
1	Rain water harvesting & Recharge pits at stations and viaducts of the alignment- Construction of recharge pits along the median (pier line) at each pier location along the metro alignment and within the depots and stations to facilitate percolation of runoff water in to the ground as per approved design and drawing developed by central water board.	Nos.	846	₹ 1,00,000.00	₹ 8,46,00,000.00	a). Nos. of Piers for Phase-2A = 638 b). Nos. of Piers for Phase-2B = 1055 **Total Nos. of Piers =1693** 1 pit per 2 Piers, 846 pits for 1693 Nos. of piers.
Total					**₹ 8,46,00,000.00**	

Source: Bengaluru Metro Rail Corporation Limited.

84. A small stretch of the proposed Phase 2B line in the Yelahanka Air Force zone is considered sensitive and would be developed as cut-and-cover tunnel for about 800 m length. The reason for this design choice is to avoid interference with radio frequency and not strictly from a climate change angle. However, there are possibilities of tunnel flooding (i) from ramps leading in and out of the tunnels, and (ii) by the open gaps left between the cut-and-cover tunnels.

85. Proper waterproofing on the outer surface of the reinforced cement concrete box will be ensured to avoid any leakage of water into the cut-and-cover section. Protection against the floodwater entering into the cut-and-cover will be provided by constructing parapet/curtain walls for sufficient height. There is a possibility of rainwater entering into the cut-and-cover from open ramps. The leakage, if any, within the cut-and-cover despite waterproofing treatment, will be directed toward the sump through side drains with proper gradient. Water collected in the sump at either end of the cut-and-cover will be dewatered by using suitable pumping system. The tunnel flood proofing cost is given below.

Table A3.9: Cost of Climate Adaptation for Cut-and-Cover Segment of Phase 2B

Sl. No.	**Description**	**Approximate Cost** (Indian rupees)
1	Waterproofing to cut-and-cover section walls and raft to arrest seepage of underground water	2.00 Cr.
2	Collection sump with pumping system	0.30 Cr.
3	Parapet/curtain wall to prevent flooding	0.20 Cr.
	TOTAL	**2.50 Cr.**

Cr. = crore.
Source: Bengaluru Metro Rail Corporation Limited.

VIII. CONCLUSION

84. This CRVA for Bengaluru metro projects Phase 2A and Phase 2B attempts to provide a wide-ranging discussion of climate risks and vulnerabilities for the said projects, yet the subject matter related to climate impacts may still appear to be generic. Climate proofing of new infrastructure projects can be challenging, and the scheme to delve into every seemingly promising adaptation measure without strong justifications supported by data and updated information may tend to result in an uneconomical project.

85. Technological advancements can help build resilience to climatic hazards even if not specifically targeting climate change, although climate change might produce new kinds of hazards and threats in the future. The DPRs of Bengaluru metro projects Phase 2A and Phase

2B are said to adhere to the latest standards and specifications issued by the Ministry of Housing and Urban Affairs of the Government of India. In addition, the BMRCL has made efforts to study the norms and parameters followed by other metro systems in various cities of India. The DPRs mention that certain modifications to design standards have been made that keep in view technological innovation and specific needs of Bengaluru city.

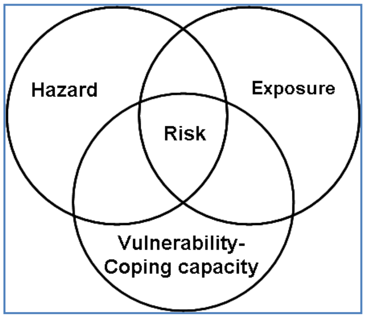
86. The DPRs recognize the risk of flooding of the Bengaluru city roads as a foremost disaster-causing concern due to enhanced contribution of rainfall runoffs by the elevated viaducts to water logging of the already flooded city roads. As an alleviation measure, water harvesting from elevated structures and from rooftops of elevated stations have been proposed in the design of Phase 2A and Phase 2B metro lines. Flood-prevention measures were also considered along the cut-and-cover portion in the Yelahanka Air Force Zone in Phase 2B.

87. Lastly, not all vulnerabilities and adverse consequences of climate change can be avoided through adaptation alone, but the BMRCL can significantly reduce the extent of damage through proactive actions to avoid, prepare for, and respond to climate change as future climate variation is bound to amplify existing climate-related risks creating new risks. Iterative adaptation responses can be achieved in later development and maintenance cycles based on experience and emerging information and technology. Given the many uncertainties and the costs involved, it is not advisable to make decisions at the outset nor is it possible or necessary to do every visualized adaptation measure at one go.

GLOSSARY OF TERMS ON CLIMATE CHANGE

The following terms and terminologies used in climate change issues are sourced from the International Union for Conservation of Nature.[1]	
Adaptation	Adjustment in natural or human systems to a new or changing environment is known as adaptation. Adaptation is a process by which individuals, communities and countries seek to cope with the consequences of climate change.
Adaptability	The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences is known as adaptability.
Adaptation Assessment	The practice of identifying options to adapt to climate change effects and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility is known as adaptation assessment.
Adaptation Deficits	Failure to adapt adequately to existing climate risks largely accounts for the adaptation deficit. As climate change accelerates, the adaptation deficit has the potential to rise much higher unless a serious adaptation program is implemented.
Adaptation to Climate Change	An initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects is known as adaptation to climate change.
Climate Change	It refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land-use.
Climate Change Mitigation	Strategies and policies that reduce the concentration of greenhouse gases in the atmosphere either by reducing their emissions or by increasing their capture is known as climate change mitigation.
Climate Change Scenario	A coherent and internally consistent description of the change in climate by a certain time in the future using a specific modeling technique and under specific assumptions about the growth of greenhouse gas and other emissions and about other factors that may influence climate in the future is known as climate change scenario. A “climate change scenario” is the difference between a climate scenario and the current climate.
Climate Change Vulnerability Assessment	A range of tools that exist to help communities understand the hazards that affect them and take appropriate measures to minimize their potential impact is known as climate change vulnerability assessment.
Climate Risk	The likelihood that the harmful effects will happen is known as climate risk or it is a measure of the probability of harm to life, property, and the environment that would occur if a hazard took place. Risk can also be considered as the combination of an event, its likelihood and its consequences, i.e., risk equals the probability of climate hazard multiplied by a given system’s vulnerability
Climate Trend	The general direction in which climate factors such as average annual temperature or rainfall tend to move over time is known as climate trend.
Climate Variability	Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all

[1] International Union for Conservation of Nature. 2011. Terminologies Used in Climate Change.

	spatial and temporal scales beyond that of individual weather events is known as climate variability
	Concept of Risk:[2] In the context of natural hazards, "risk" not only represents the possibility that a hazard event could occur, but also its likelihood and consequences. There are many ways it can impact a community, from the destruction of property and infrastructure, through to injuries and casualties, to influencing economic activity. As can be visualized by the figure on the left, the intersection of hazard, exposure, and vulnerability yields the risk (Reese and Schmidt 2008).

[2] National Institute of Water and Atmospheric Research. Risk and vulnerability.

BIBLIOGRAPHY

Asian Development Bank. 2014. Climate Proofing ADB Investment in the Transport Sector, Initial Experience. Manila.

Bangalore Development Authority. Revised Master Plan 2031 for Bengaluru Region.

Bengaluru Metro Rail Corporation Limited. 2019. ORR Metro Line on Outer Ring Road from Central Silk Board (CSB) Junction to KR Puram. Detailed Project Report (DPR) for Phase 2A of Bengaluru Metro. Volume I. October (Revised).

Bengaluru Metro Rail Corporation Limited. 2019. From KR Puram to Kempegowda International Airport. Detailed Project Report (DPR) for Phase 2B of Bengaluru Metro. Volume I. October (Revised).

Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science. 2017. Frequent Floods in Bangalore: Causes and Remedial Measures. Bangalore, Karnataka. August.

Environmental Management & Policy Research Institute (EMPRI) and The Energy and Resources Institute. 2013. Karnataka Climate Change Action Plan (KCCAP), First Assessment, 2012.

Government of India, National Disaster Management Authority (DMA). 2010. National Disaster Management Guidelines, Management of Urban Flooding, NDMA. September.

Government of India. 2013. State Level Climate Change Trends in India; IMD Monogram No: ESSO/IMD/EMRC/02/2013.

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

Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Summary for Policymakers, Technical Summary and Frequently Asked Questions.

International Union for Conservation of Nature. 2011. Terminologies Used in Climate Change.

Jogesh, A. and Dubash, Navroz K. 2014. An Analysis of Karnataka's Action Plan on Climate Change. February.

Meteoblue.com. Climate Bengaluru.

Ministry of Housing and Urban Affairs. 2017. Metro Rail Policy.

National Disaster Management Authority. 2016. Guidelines for Preparation of Action Plan – Prevention and Management of Heat-Wave.

Open City Urban Data Portal. 2019. Bengaluru Comprehensive Mobility Plan (CMP) Draft – October and 18 December.

Prasad, R. and Narayanan, P. 2016. Vulnerability Assessment of Flood Affected Locations of Bangalore by Using Multi-Criteria Evaluation. School of Earth Science, Central University of Karnataka.

Suttha Muttha. 2012. Namma Bangalore-Mysore: The cities that never cease to surprise. 16 November.

ThinkHazard!: Global Facility for Disaster Reduction and Recovery (GFDRR). http://thinkhazard.org/en.

World Bank. Final Report submitted by Bangalore Climate Change Initiative – Karnataka (BCCI-K); A Project funded by World Bank.

World Bank Group. Climate Change Knowledge Portal. India Climate Data Projections.