YÜKSEL PROJE

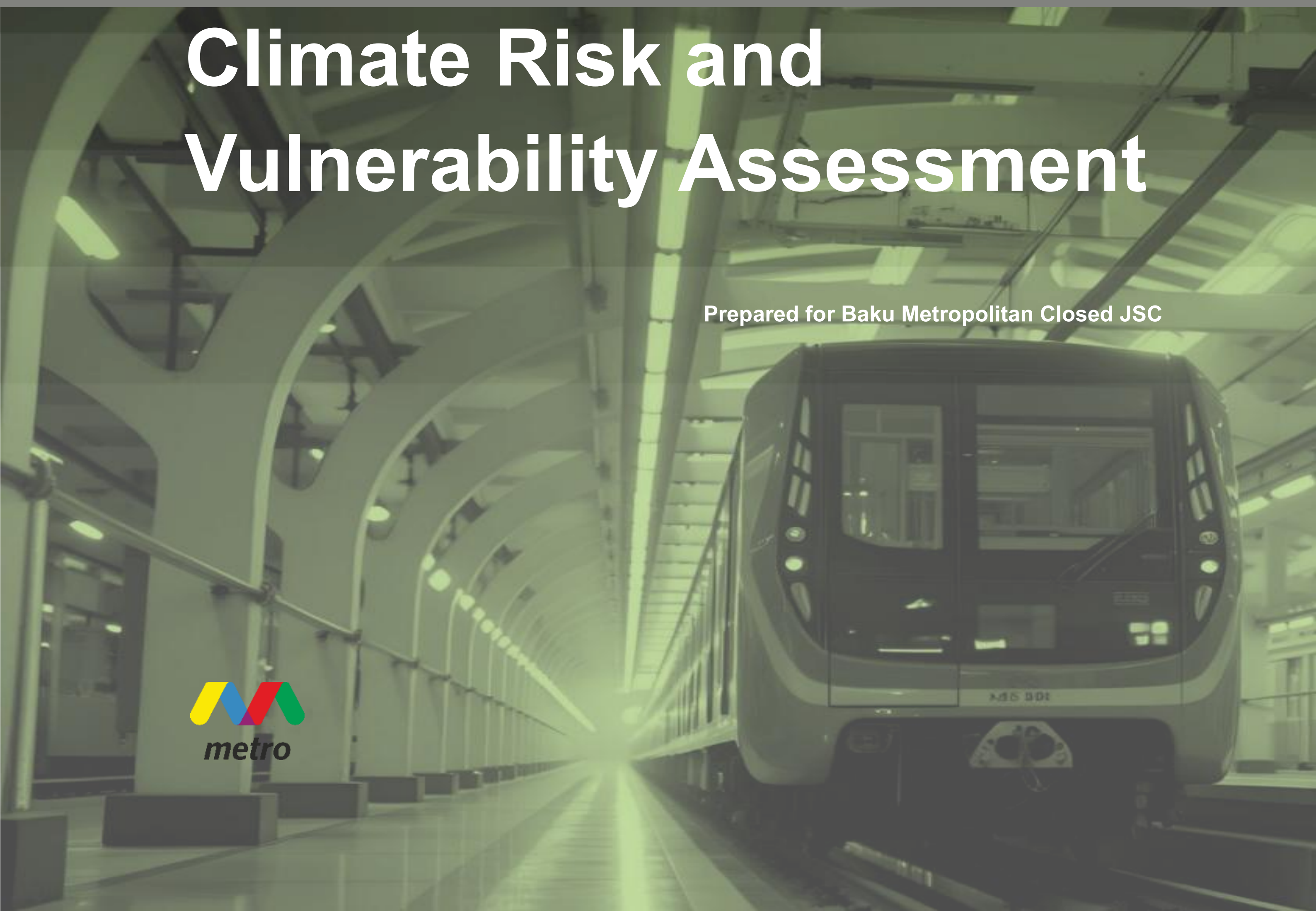
GREEN ENGINEERING

# BAKU METRO EXPANSION PROJECT

## GREEN LINE

# Climate Risk and Vulnerability Assessment

Prepared for Baku Metropolitan Closed JSC



metro

## Quality Information

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## List of Acronyms

| | |
|---|---|
| AIIB | Asian Infrastructure Investment Bank |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BM | Baku Metro |
| BMEP | Baku Metro Expansion Project |
| BTR1 | First Biennial Transparency Report |
| CAPEX | Capital Expenditure |
| CHSP | Community Health and Safety Plan |
| CNG/LPG | Compressed Natural Gas / Liquefied Petroleum Gas |
| COP21 | 21st Conference of the Parties |
| CRA | Climate Resilience Assessment |
| CRVA | Climate Risk and Vulnerability Assessment |
| EPRP | Emergency Preparedness and Response Plan |
| ESAP | Environmental and Social Action Plan |
| ESHS | Environmental, Social, Health and Safety |
| ESIA | Environmental and Social Impact Assessment |
| ESMP | Environmental and Social Management Plan |
| GDP | Gross Domestic Product |
| GEV | Generalized Extreme Value |
| GHG | Greenhouse Gas |
| HEC-HMS | Hydrologic Engineering Center – Hydrologic Modeling System |

| | |
|---|---|
| HEC-RAS | Hydrologic Engineering Center – River Analysis System |
| HVAC | Heating, Ventilation and Air Conditioning |
| IPPU | Industrial Processes and Product Use |
| O&M | Operation and Maintenance |

# 1. Project Overview

The Baku Metro is a key component of urban transport in Azerbaijan's capital, providing fast, reliable, and high-capacity mobility across the city. Since its opening in 1967, the system has expanded significantly and currently comprises 27 stations across three lines, serving approximately 597,000 passengers per day. As part of ongoing efforts to improve urban mobility, the Baku Metro Expansion Project (BMEP) has been developed under the State Program for the Improvement of Transport Infrastructure (2025–2030). Within this framework, the Green Line Extension Project ("the Project")—which includes the extension between Xatai and Hazi Aslanov (Stations Y-14, Y-15, Y-16 and Y-17, approximately 7 km) aims to enhance system capacity, improve operational efficiency.

In addition to its transport and environmental benefits, the Project represents a strategic opportunity to integrate climate resilience into long-term infrastructure planning. This Climate Risk and Vulnerability Assessment (CRVA) is therefore directly linked to the Project's design and assessment process and aims to evaluate how projected climate hazards may affect the specific assets and components of the Green Line Extension. The objective is to ensure that climate-related risks are systematically identified and addressed through appropriate design and operational measures ("climate proofing") integrated into the Project.

Baku's geographical location on the Absheron Peninsula, influenced by both continental and Caspian Sea conditions, creates a distinct climate risk profile. The city is characterized by a semi-arid climate with hot summers; however, climate projections indicate significant increases in average and extreme temperatures, as well as more frequent and intense heatwaves. In parallel, while total annual precipitation may remain relatively stable, short-duration, high-intensity rainfall events are expected to intensify, increasing the risk of urban flooding and water ingress into underground infrastructure.

These climate trends, combined with existing urban vulnerabilities such as dense development patterns and drainage capacity constraints, may pose risks to metro infrastructure, including thermal stress on systems, increased cooling demand, and flooding of underground assets. In this context, the Climate Risk and Vulnerability Assessment (CRVA) has been undertaken to identify key climate risks affecting the Project and to define appropriate adaptation measures, ensuring that the metro system remains safe, reliable, and resilient under future climate conditions.

# 2. Legislative Framework, Policy and Guidance

International

**UN Framework Convention on Climate Change (UNFCCC)**

The Republic of Azerbaijan has been a part of the UNFCCC since 1992, and the country's commitment to reducing the climate change impacts and creating resilience against it is followed and supported by the UNFCCC. Azerbaijan submitted the ***First Biennial Transparency Report (BTR1)*** in November 2024. BTR1 evaluates primary sectors such as energy, agriculture, land use, forestry, Waste, Industrial Processes and Product Use, and their effect on GHG emissions. The report mentions the current status of climate change impacts in the country with detailed methodology, completed actions, and progress on the promises.

**EU4Climate**

The Republic of Azerbaijan is part of the 6 countries that the EU supports for climate action in line with *the Paris Agreement* in matters such as adaptation planning, resilience policies, and low emissions development. Extreme events of flooding, drought, and heat stress are expected in Azerbaijan.

**The Republic of Azerbaijan Nationally Determined Contributions (NDCs) – 2023**

The Republic of Azerbaijan updated its NDCs in 2023 in accordance with the *Paris Agreement* and COP21 decisions. First NDCs published in 2015 and promised 35% reduction in greenhouse gas emissions until 2050, taking the base year as 1990. In the updated version, the Republic of Azerbaijan promises a 40% reduction in greenhouse gas emissions. NDC report mentions the attention on smart cities around the country. The country also has an intention to create a "Net Zero Emissions" zone in the liberated territories after the war by 2050 with the help of international consultants. Tax and customs tariff reduction is given to companies investing in innovation to reduce the impact of climate change under related circumstances.

- **Energy Sector:** Azerbaijan is developing laws, roadmaps, and international partnerships to accelerate the use of renewable energy, increase energy efficiency, and involve the private sector in the process. Preventive measures include reducing energy losses, promoting environmentally friendly transportation, and implementing circular economy practices.
- **Heat Supply:** Technical rules and procedures for the operation of electrical and thermal facilities have been adopted to ensure efficiency in the public services sector and regulate producer-consumer relations.
- **Transport:** In transportation, the focus has been on developing north-south and east-west corridors, constructing the Alat Port, and promoting the use of environmentally friendly vehicles. Information platforms for electric vehicles have been created.
- **IPPU (Industrial Processes and Product Use):** Industry-related greenhouse gas emissions come from the mining, chemical, and metallurgical sectors.
- **Agriculture, Land Use, Land Use Change and Forestry:** Agriculture ranks second in emissions after the energy sector; climate-friendly agricultural technologies and livestock waste management are prominent measures.
- **Forestry:** Afforestation and increasing green areas play an important role in greenhouse gas absorption under the "Azerbaijan 2030" strategy.
- **Waste Sector:** The waste management strategy aims to strengthen the recycling market, create opportunities for investors, and develop the waste collection system with paid services.

<u>National</u>

**Initial National Adaptation Plan – 2024**

The Initial National Adaptation Plan was declared in 2024 under UNFCCC guidelines to build up resilience to climate change. The 5 most vulnerable fields are given as water sector, agriculture, health, climate-related hazards and disasters, and coastal and mountain ecosystems. The plan investigates the current status of climate change in the country, creating risk maps and a vulnerability index, and highlights the country-specific problems, such as a decrease in water level in the Caspian Sea. Gender, indigenous people, and youth considerations are made. Climate-related problems and corresponding organizations are identified with outputs. Suggested policies include:

- Developing a delivery model for climate services
- Improving observations, monitoring, modelling, and prediction of climate and its impact
- Enhancing the dissemination and communication of climate risk information and multi-hazard early warning
- Enhancing climate risk management capacity.

**Azerbaijan 2030: National Priorities for Socio-Economic Development – 2021**

The decree was signed by the President of the Republic of Azerbaijan. The 5 national priorities to achieve until 2030 declared in 2021 include an article about a high-quality ecological environment, and green energy: “A country of clean environment and 'green growth'” ***2022-2026 Social and Economic Development Strategy*** is a strategy implemented for 5 national priorities and includes strategic frameworks, key performance indicators, SDG mapping, implementation plan of decided actions for clean environment and green growth country.

**National Sustainable Energy Action Plan of Azerbaijan**

The action plan investigates the current status in the case of production and consumption of different energy forms and focuses on energy efficiency and renewable energies as future actions. Expectations and indicators are defined, and the GHG emissions caused by the energy sector are shown, which are dominant across different sectors. With a mention of challenges in planned activities, a detailed action plan including a timeline and the primary organization responsible is given.

## 2.1 Nationally Determined Contribution of Azerbaijan and Relationship with this Study

The NDC 3.0 report of Azerbaijan presents a detailed roadmap and mitigation strategies for all key sectors, highlighting the importance of multi-stakeholder engagement and the need for technological upgrades. It sets out clear, actionable plans and identifies the necessary conditions to achieve measurable and meaningful climate outcomes. The report underscores the role of both public and private sector investments, alongside international support, to successfully finance Azerbaijan’s climate ambitions. This approach not only reinforces the country’s Paris Agreement commitments but also advances its sustainable development policies and international climate cooperation.

As part of NDC 3.0, the baseline year for calculating emissions reductions was changed from 2016 to 2022, and the 1990 emissions reference value was updated to align with the latest IPCC methodologies. This revision ensures greater accuracy in sectoral emissions forecasts and enhances the reliability of projections related to climate mitigation levers. By doing so, it enables Azerbaijan to set more realistic yet ambitious climate targets and includes estimations of the resources needed to achieve them.

Figure 2-1 summarizes the comparison between NDC 2 and NDC 3.0.

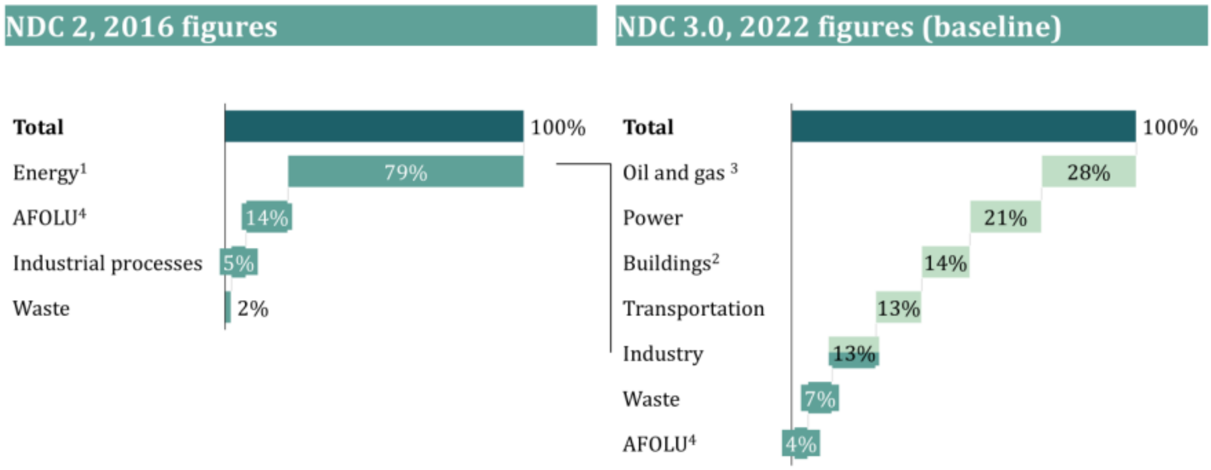


**Figure 2-1 Summary of Comparison Between NDC 2 and NDC 3.0[1]**

Transportation Sector

The transportation sector plays a vital role in Azerbaijan's economy, accounting for around 6% of the national GDP. This sector is supported by an extensive network that includes highways, domestic railways, air transport, and maritime routes. Annually, road transport consumes approximately 2,704 kilotonnes of fuel, including gasoline, diesel, CNG/LPG, and electricity. In 2022, the combined fuel consumption of domestic rail, aviation, and maritime activities reached 220 kilotonnes, comprising diesel, aviation fuel, and marine oil.

In line with the country's economic development, growing population, and increasing private vehicle use, transportation-related greenhouse gas (GHG) emissions have risen significantly. In 2022, the sector emitted 9,3 million tonnes of $CO_2$ equivalent, representing 13% of Azerbaijan's total GHG output. Road transport dominates these emissions, contributing 92% (8,6 $MtCO_2e$), largely due to gasoline and diesel engines in internal combustion vehicles. Domestic aviation accounts for 5% (0,5 $MtCO_2e$), while maritime and rail transportation contribute 2% and 1%, respectively—mainly from marine fuels and diesel-powered rail locomotives.

Planned measures for transportation sectors by 2035 is given in Figure 2-2.

[1] https://unfccc.int/reports?f%5B0%5D=corporate_author%3A103

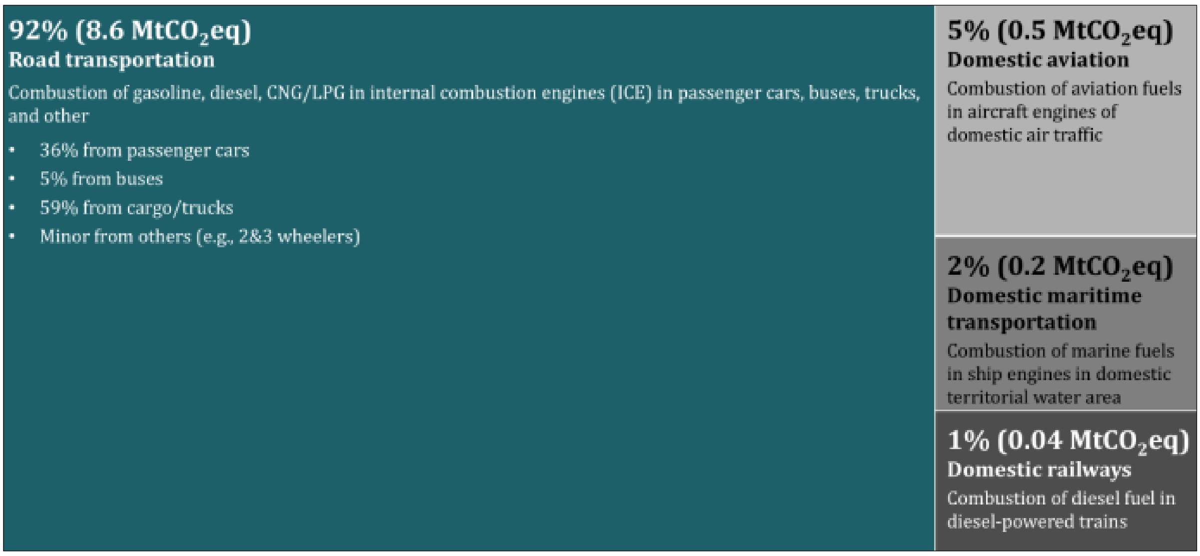


**Figure 2-2 Planned Measures for Transportation Sectors by 2035**

Structural and operational upgrades

• Expand and modernize the public transportation networks, including buses, trains, and metro

• Incentivize behavioural change toward increased usage of public transportation and micro-mobility

• Increase the use of and expand the railway network

Electrification

• Plan the initial retirement of the ICE fleet and renew the public transportation park

• Increase EV share in passenger car, bus, and truck fleets

• Support the adoption of EVs through incentive programs

Biofuels

• Adopt biofuels in transportation

• Utilize biofuel blending in aviation fuel activity

As can be seen from the summary information shared above regarding the NDC's connection with the transportation sector, the metro construction project, which is the focus of this study, will be a crucial step in Azerbaijan's ability to meet its NDC targets. The following sections of this document provide insights into climate change-related risks and examples of adaptation.

# 3. Assessment Methodology

## 3.1 Data Sources

This study is based on the NASA Earth Exchange Global Daily Downscaled Projections dataset (NEX-GDDP-CMIP6), which provides statistically downscaled and bias-corrected outputs from global climate models participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) (Thrasher et al., 2022)[2].

The dataset includes both historical simulations (1950–2014) and future projections (2015–2100), with a spatial resolution of 0.25°. The following key climate variables were used in the analysis:

- Near-surface air temperature (mean, maximum, minimum)
- Precipitation
- Near-surface wind speed

Two Shared Socioeconomic Pathway (SSP) scenarios were selected to represent a range of plausible future climate conditions:

- SSP2-4.5: intermediate stabilization scenario
- SSP5-8.5: high-emission scenario

In addition to climate model data, the ERA5-Land reanalysis dataset was used to characterize observed baseline climate conditions for the study area.

## 3.2 Model Selection

The NEX-GDDP-CMIP6 dataset provides outputs from 35 global climate models. However, not all models were suitable for consistent multi-variable analysis across the study period.

A subset of 32 models was therefore selected based on data completeness and consistency criteria. Models with incomplete temporal coverage, missing variables (e.g., temperature, precipitation, or wind) were excluded from the analysis.

This approach ensures that all selected models provide a harmonized dataset across variables and scenarios, enabling a robust and internally consistent multi-model assessment.

## 3.3 Ensemble Approach and Uncertainty Representation

Climate projections inherently contain uncertainty arising from model structure, parameterization, and natural climate variability. To account for this, a multi-model ensemble approach was adopted.

[2] Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T., & Nemani, R. (2022). NASA Global Daily Downscaled Projections, CMIP6. Scientific Data, 9(1). https://doi.org/10.1038/s41597-022-01393-4

Rather than relying on a single model, projections from the selected 32 models were combined to derive ensemble statistics. The following metrics were used:

- Median (p50): represents the central estimate of projected change
- 10th percentile (p10): represents the lower bound of projections
- 90th percentile (p90): represents the upper bound of projections

The use of the ensemble median provides a robust estimate that reduces the influence of individual model biases, while the p10–p90 range captures the spread of projections and associated uncertainty.

## 3.4 Baseline and Projection Framework

A clear distinction is made between observed climate conditions and model-based projections:

- **Observed / reanalysis data (ERA5-Land):** used to describe baseline climate conditions
- **CMIP6 historical simulations:** represent model reconstructions of past climate and are used for model-based comparison
- **CMIP6 future projections:** used to assess potential future climate conditions under different emission scenarios

It is important to note that historical simulations from climate models do not represent actual observed climate, but rather model-generated approximations of past conditions. Therefore, they are not treated as equivalent to observational datasets.

A baseline reference period of 1981–2010 was used to calculate climate anomalies and assess changes in future periods.

## 3.5 Hazard-Oriented Climate Analysis

The analysis was structured to support climate risk and vulnerability assessment (CRVA) by linking climate variables to relevant hazards affecting metro infrastructure.

The following hazard categories were defined:

- Heat-related hazards: derived from mean, maximum, and minimum temperature projections, including heatwave conditions and increased thermal stress
- Hydrological hazards: derived from precipitation and extreme rainfall analysis, including pluvial flooding risks
- Wind-related hazards: derived from near-surface wind speed projections and extreme wind considerations
- Coastal hazards: associated with potential fluctuations in Caspian Sea levels

For precipitation extremes, annual maximum daily precipitation values were extracted and fitted to a Generalized Extreme Value (GEV) distribution. Return period estimates (e.g., 100-year events) were calculated for both historical and future periods.

## 3.6 Trend Analysis

To assess long-term trends in climate variables, the non-parametric Mann-Kendall test was applied. This method is widely used in climate studies to detect statistically significant trends in time series data.

The test provides:

- Tau coefficient: indicating the direction and strength of the trend
- p-value: indicating statistical significance

This analysis was applied to both historical and future periods to evaluate the evolution of key climate variables over time.

# 4. Baseline Climate Conditions

Baseline climate conditions for the study area were derived primarily from the ERA5-Land reanalysis dataset, complemented by available observational records. However, due to the limited temporal coverage of long-term observational datasets in the study area, ERA5-Land was used as the main source to ensure a continuous and consistent time series analysis over multiple decades.

This section describes observed temperature, precipitation, and wind characteristics, which provide the basis for comparison with future climate projections. In addition to long-term averages, temporal variability and historical trends are analyzed to better understand how climate conditions have evolved over recent decades.

## 4.1 Temperature (Observed Conditions)

To assess historical changes in temperature, annual mean temperature time series for the period 1950–2020 were analyzed based on ERA5 Land data.

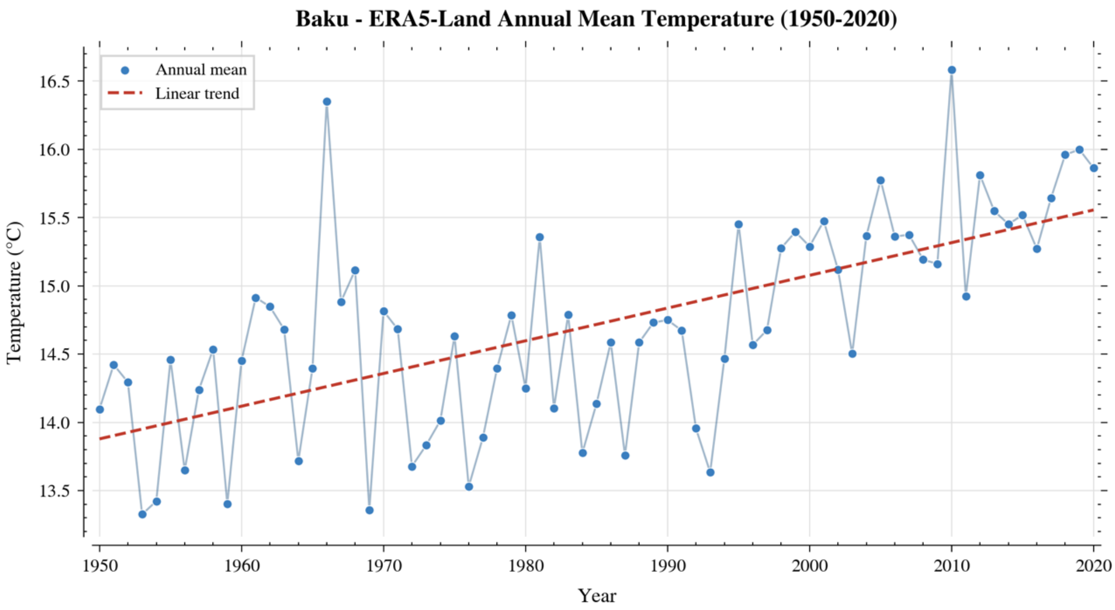


**Figure 4-1 Annual Mean Temperature (1950–2023) and Linear Trend for Baku based on ERA5-Land Data**

The time series indicates a clear long-term warming trend in the study area. A consistent increase in annual mean temperature is observed, particularly from the 1980s onwards. The fitted linear trend shows an increase of approximately 0.26°C per decade, highlighting a significant and persistent warming signal over the analysis period. Recent decades are consistently warmer than the 1981–2010 baseline period, confirming that climate change impacts are already evident in the region. From an infrastructure perspective, this indicates that baseline climate conditions are already shifting, which has direct implications for thermal loads, cooling demand, and long-term system performance.

## 4.2 Precipitation (Observed Conditions)

Precipitation in the Baku region is generally low and irregular, reflecting the semi-arid climate conditions of the Absheron Peninsula. Short-duration extreme rainfall events are particularly relevant for urban infrastructure, as they can generate rapid surface runoff and lead to localized flooding. To assess such extremes, the annual maximum 1-day precipitation (Rx1day) index was analysed for the period 1950–2020 using ERA5-Land data (Figure 4-2).

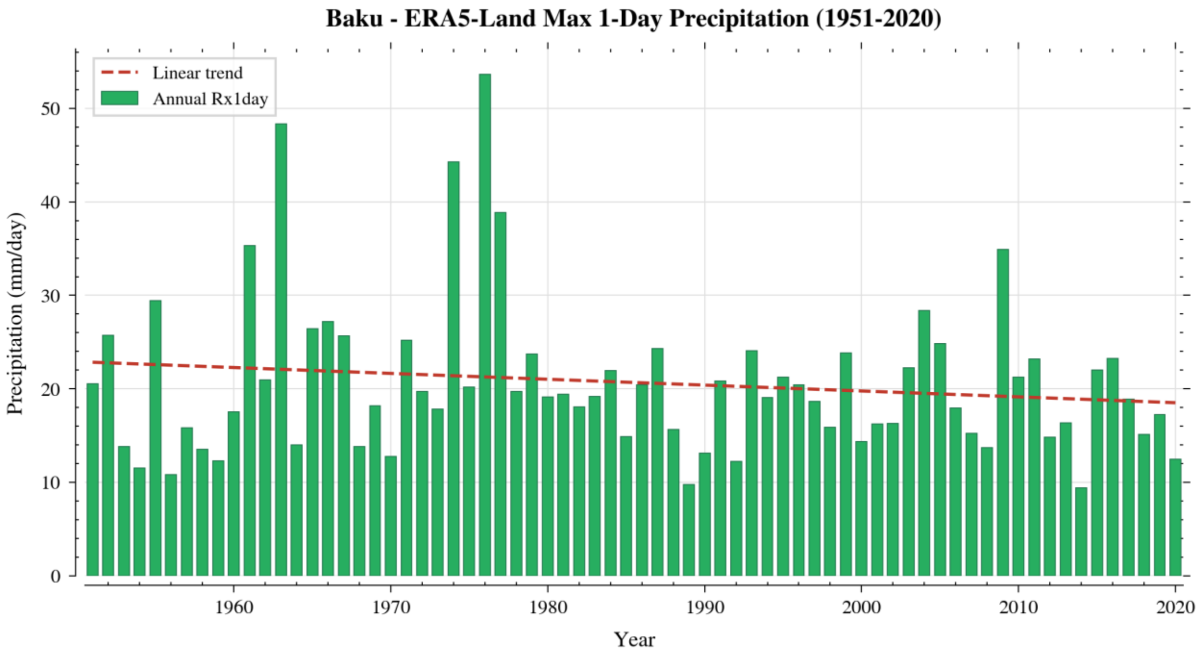


**Figure 4-2 The Annual Maximum 1-day Precipitation (Rx1day) Index (1950-2020)**

The results show year-to-year variability in extreme precipitation, with several years exhibiting significantly higher daily rainfall totals compared to the long-term average. Peak values exceed 50 mm/day, indicating that intense rainfall events, although infrequent, can occur in the region. The fitted linear trend suggests a slight decreasing tendency in maximum daily precipitation over the analysis period. However, this trend is weak compared to the high interannual variability, and no clear long-term increase in extreme precipitation is evident from historical observations alone. Even under historically stable conditions, short-duration high-intensity rainfall events remain a critical driver of urban flooding.

## 4.3 Wind (Observed Conditions)

Wind is a defining climatic characteristic of the Baku region, influenced by its location along the Caspian Sea and the surrounding topography, which creates a natural wind corridor. From an infrastructure perspective, extreme wind conditions are more relevant than average wind speeds, as they govern structural loading, operational safety, and the performance of above-ground components.

To assess these conditions, the annual maximum near-surface wind speed was analyzed for the period 1950–2020 using ERA5-Land data (Figure 4-3).

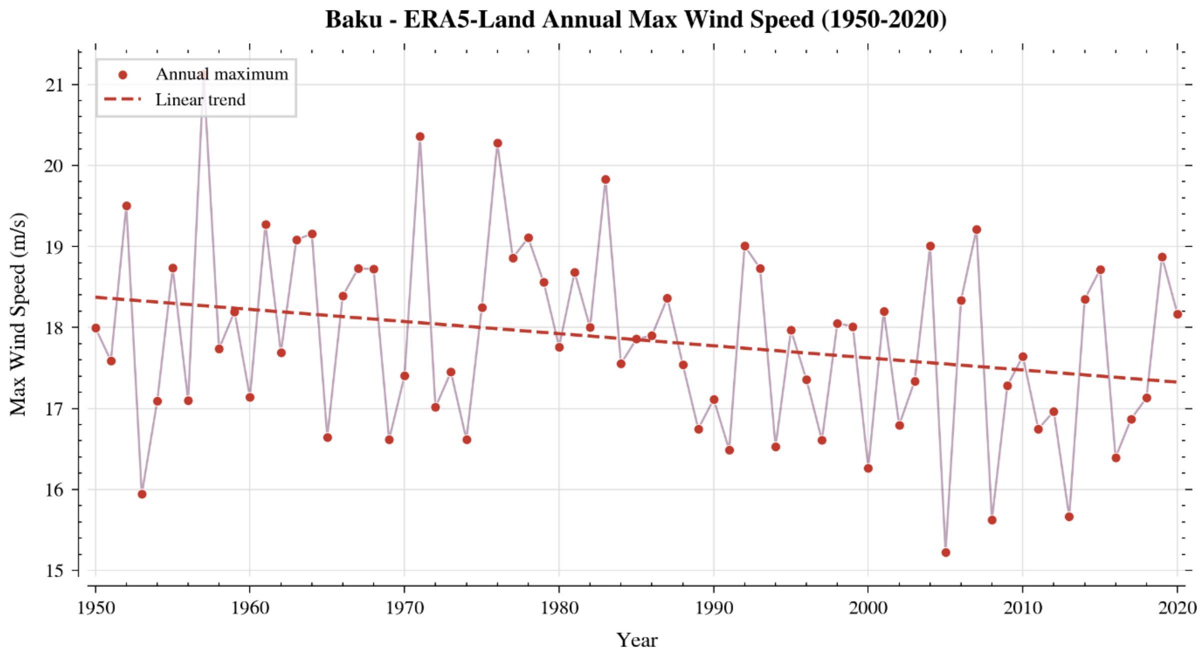


**Figure 4-3 The Annual Maximum Near-Surface Wind Speed for the Period 1950–2020**

The results indicate that annual maximum wind speeds exhibit substantial interannual variability, with values generally ranging between approximately 15 and 21 m/s. Several years show pronounced peaks, highlighting the occurrence of episodic high-wind events in the region. The fitted linear trend suggests a slight decreasing tendency in maximum wind speed over the analysis period. However, this trend is relatively weak compared to the magnitude of year-to-year variability and does not indicate a significant long-term reduction in extreme wind potential. These results indicate that extreme wind events may be a consideration for design. Short-duration high-intensity wind conditions could be considered for structural systems, above-ground components, and ventilation infrastructure.

# 5. Future Climate Projections

Future climate projections for the study area were derived from the NEX-GDDP-CMIP6 dataset, using an ensemble of 32 global climate models. Two emission scenarios were considered:

- SSP2-4.5: intermediate stabilization scenario
- SSP5-8.5: high-emission scenario

The reference period 1981–2010 was used as a baseline for calculating anomalies. The historical simulations from the climate models were used only to establish this baseline and calculate anomalies and were not treated as equivalent to observed climate conditions. To account for model uncertainty, results are presented using the ensemble median (p50), along with the 10th–90th percentile range (p10–p90).

## 5.1 Daily Near-Surface Air Temperature

Figure 5-1 presents the average temperature anomaly relative to the 1981-2010 period, showing the yearly mean temperature anomalies derived from daily observations on two different scenarios: SSP245 and SSP585.

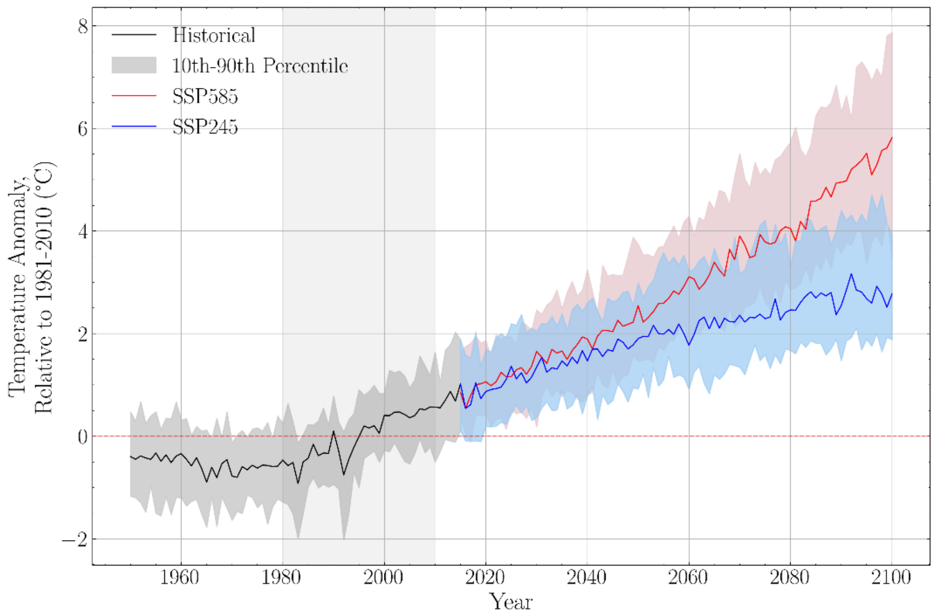


**Figure 5-1 Average Temperature Anomaly Relative to the 1981-2010 Period**

This graph presents projections from 32 climate models, with the black line showing their median and the shaded area representing the 10th–90th percentile range, illustrating the spread of model outputs. The median temperature anomaly begins to rise noticeably around the mid-1980s, indicating a steady increase relative to the 1981–2010 baseline. During 2000–2015, average annual temperatures were about 1 °C higher than in the baseline period.

Both future scenarios show a marked increase in temperature anomalies compared to the historical period, with SSP585 exhibiting a stronger warming trend. The median lines of SSP245 (blue) and SSP585 (red) diverge substantially in the second half of the century, reflecting different emissions pathways. By the end of the century, SSP245 projects a warming of about 2–3 °C, while SSP585 suggests a much greater increase of roughly 5–6 °C.

Figure 5-2 also shows the mean daily temperature (left) and anomalies (right) for the period 2080-2100 compared to the baseline of 1981-2010 under SSP585, across Baku Region.

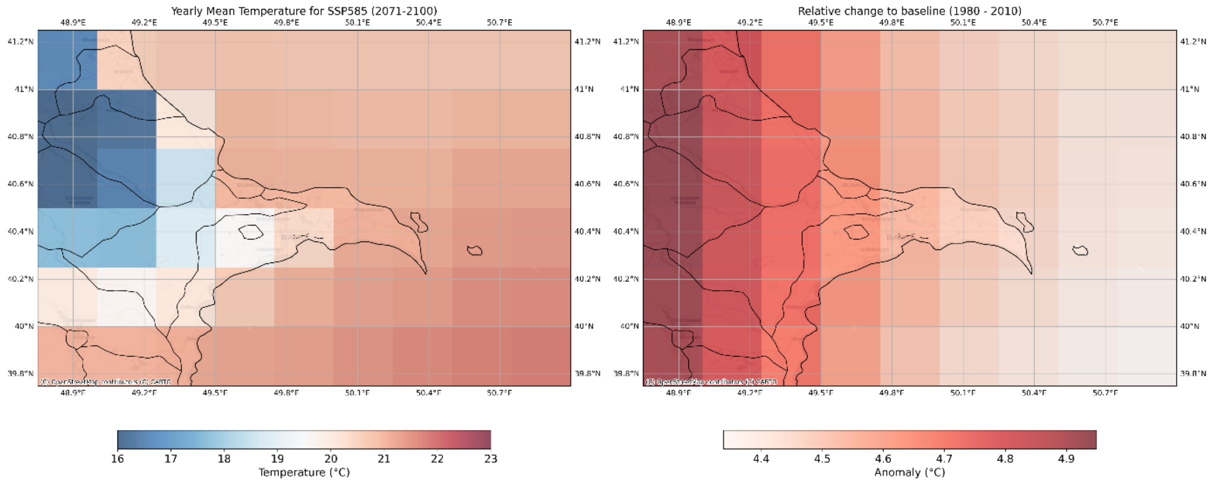


**Figure 5-2 The Mean Daily Temperature Anomalies for the Period 2080-2100 Compared to the Baseline of 1981-2010**

The projected yearly mean temperature maps for the Baku region shows both the spatial distribution and magnitude of change reflecting the influence of topography and regional climate dynamics. The projected mean temperature, revealing that most of the Baku will experience annual mean temperatures between approximately 20°C and 23°C. Coastal areas along the Caspian Sea exhibit relatively lower temperatures. The strongest warming occurs inland, indicating that continental areas will heat more rapidly than the coast. Even along the Caspian coast, where the sea provides some moderation, anomalies exceed +4°C.

## 5.2 Daily Maximum Near-Surface Air Temperature

Figure 5-3 presents the maximum temperature anomaly relative to the 1981-2010 period.

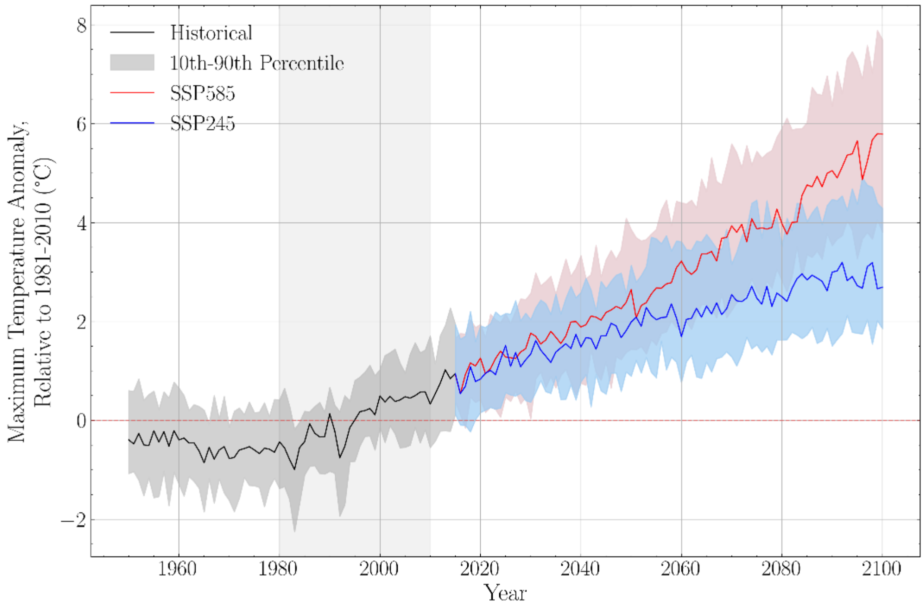


**Figure 5-3 Maximum Temperature Anomaly Relative to the 1981-2010 Period**

Both scenarios show a significant increase in maximum temperature anomalies compared to the historical period, with SSP585 showing a more pronounced rise. The median lines for both scenarios indicate an upward trend in maximum temperature anomalies, with SSP585 showing a more accelerated increase compared to SSP245. The SSP585 scenario shows a more significant increase in maximum temperature anomalies, particularly after 2040, reflecting the higher greenhouse gas concentration pathway associated with SSP585.

Figure 5-4 shows the daily maximum temperature (left) and anomalies (right) for the period 2080-2100 compared to the baseline of 1981-2010 under two climate scenarios, SSP245 and SSP585.

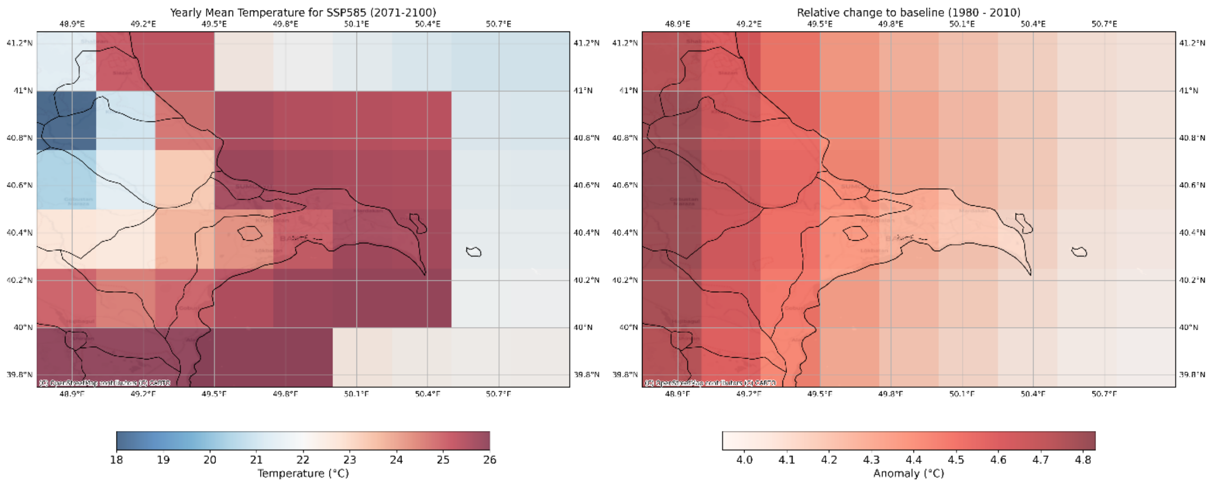


**Figure 5-4 The Maximum Daily Temperature Anomalies for the Period 2080-2100 Compared to the Baseline of 1981-2010**

Central and southern parts of Baku, including the coastal and lowland areas, show the highest projected maximums, around 30–32°C, consistent with intensified heat stress in urbanized environments. The anomaly map shows an increase in yearly mean daily maximum temperatures of 4.0 to 5°C across the region. Projections indicate Baku will experience more frequent and prolonged extreme heat, raising health risks for vulnerable groups. Urban and industrial infrastructure will experience higher thermal stress, raise cooling energy demand and reducing outdoor labor productivity.

## 5.3 Daily Minimum Near-Surface Air Temperature

Figure 5-5 presents the minimum temperature anomaly relative to the 1981-2010 period.

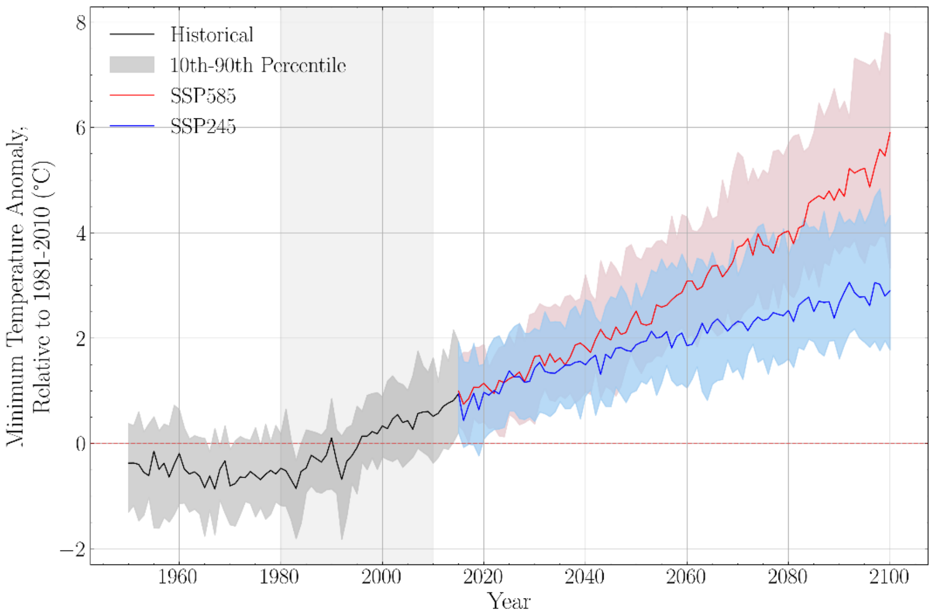


**Figure 5-5 Minimum Temperature Anomaly Relative to the 1981-2010 Period**

The historical minimum temperature anomaly shows a gradual upward trend from 1990 to around 2010, followed by a sharper increase thereafter. Historically, temperature anomalies remained relatively close to the baseline, generally fluctuating within –1 °C. Under future projections, the SSP245 scenario indicates an increase of about 2–3 °C by 2100, while the SSP585 scenario suggests a much stronger warming, with anomalies reaching up to 6 °C. Both scenarios indicate substantial warming compared to the historical period, with the high emission scenario (SSP585) resulting in a more rapid and pronounced rise in minimum temperatures.

Figure 5-6 shows the daily minimum temperature (left) and anomalies (right) for the period 2080-2100 compared to the baseline of 1981-2010 under two climate scenarios, SSP245 and SSP585.

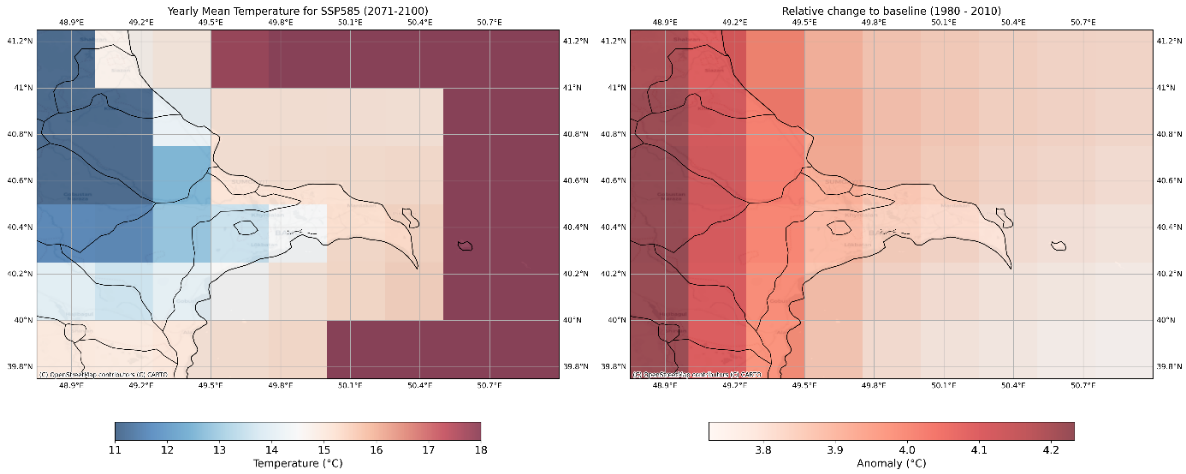


**Figure 5-6 The Minimum Daily Temperature Anomalies for the Period 2080-2100 Compared to the Baseline of 1981-2010**

The mean of daily minimum temperatures also shows a notable rise, with average night-time temperatures projected between 15°C to 16°C, roughly 3.5–4°C higher than the historical norm. Overall, these results depict a uniform and substantial rise in both maximum and minimum temperatures by the end of the century. Daytime extremes will become hotter and more prolonged, while night-time cooling will diminish significantly.

## 5.4 Precipitation Projections

### 5.4.1 Total Precipitation Changes

Projected changes in total annual precipitation were analyzed relative to the baseline period 1981–2010, using the multi-model ensemble.

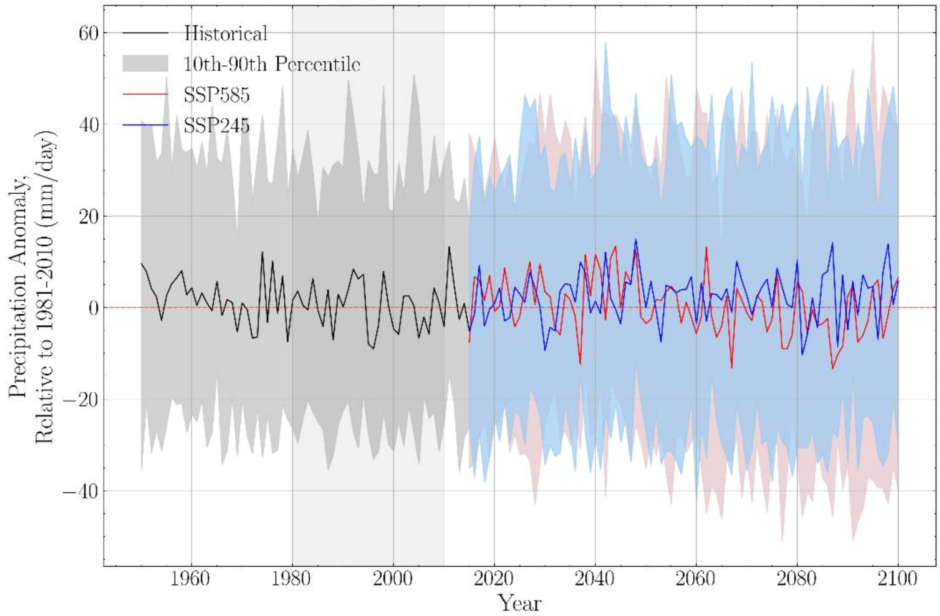


**Figure 5-7 Daily Precipitation Anomaly Relative to the 1981-2010 Period**

During the historical period (1950–2010), precipitation fluctuates around the baseline and no clear long-term trend. Beginning in the mid-21st century, both emission scenarios show slightly positive anomalies relative to the baseline, suggesting a modest increase in annual precipitation toward the end of the century. In Overall, the projections imply that while the region may experience similar precipitation conditions in future and negligible change is expected. For this reason, the analysis focuses on changes in extreme precipitation events, which are more directly linked to flood risk

### 5.4.2 Extreme Precipitation

Extreme precipitation values and their changes related to historical conditions were also analysed. Extreme precipitation refers to intense rainfall events occurring over short durations, which can generate large volumes of runoff in a limited time. Under climate change, both the intensity and frequency of such events are expected to increase in many regions, potentially leading to a higher likelihood and severity of pluvial (urban and flash) flooding, particularly where rainfall exceeds the capacity of natural and engineered drainage systems.

To assess changes in extreme rainfall, the annual maximum 1-day precipitation (Rx1day) and associated return levels were analysed using a Generalized Extreme Value (GEV) distribution. For each model, annual maximum precipitation values were extracted and fitted to the GEV distribution. Based on these fits, precipitation levels corresponding to return periods of 2, 5, 10, 50, and 100 years were estimated. The analysis was carried out for both the historical baseline period (1981–2010) and the future period (2071–2100) unde

the SSP2-4.5 and SSP5-8.5 scenarios. Finally, the ensemble median of the estimated return levels across all models was calculated to provide a robust central estimate of extreme precipitation.

The spatial distribution of 24-hour precipitation associated with the 100-year return period for the future period (2071–2100), along with its relative change compared to the baseline period, is presented in Figure 5-8 for the SSP5-8.5 scenario.

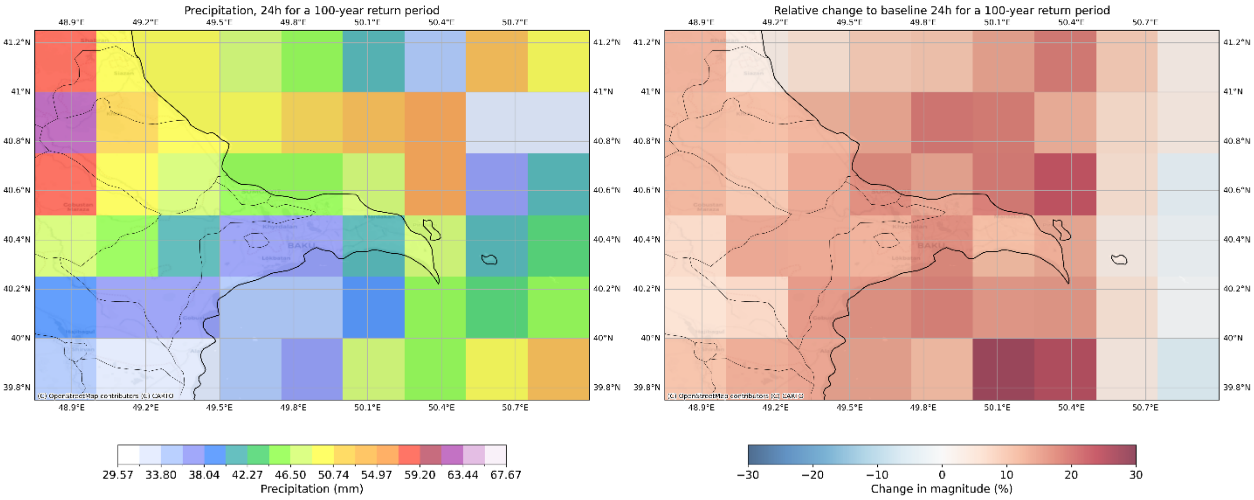


**Figure 5-8 The Daily Precipitation Anomalies for the Period 2080-2100 Compared to the Baseline of 1981-2010**

Extreme 24-hour precipitation totals for the late 21st century display that in Baku Metropolitan Area, extreme precipitation values will reach up to 45 mm for 100-year return period. The projected percentage change relative to the historical baseline shows a clear tendency toward intensification of extreme precipitation in the region. In the Baku Metropolitan Area, increases in extreme precipitation of approximately 5% to over 10% are projected, which could significantly influence the design and capacity rrrequirements of hydraulic and underground infrastructure, including metro tunnels, drainage systems, and flood protection measures.

These findings suggest that by the end of the century, extreme rainfall events in the Baku Metropolitan Area could become significantly more intense, exacerbating the risk of flash floods, riverine flooding, and urban drainage failures. The robustness of the multi-model ensemble median further strengthens the conclusion that extreme precipitation intensification is a likely outcome under SSP585, and it highlights the importance of incorporating climate change considerations into long-term planning.

## 5.5 Summary

Additionally, the Table 5-1 provides a summary of trends in various climate variables across different scenarios and periods, analyzed using the Mann-Kendall test.

**Table 5-1 Summary of Trends in Various Climate Variables Across Different Scenarios**

| Variable | Scenario | Period | Trend |
|---|---|---|---|
| Daily Near-Surface Air Temperature ($^0$C) | Historical | 1981-2020 | positive |

| Variable | Scenario | Period | Trend |
|---|---|---|---|
| Daily Near-Surface Air Temperature ($^0$C) | SSP245 | 2020-2100 | positive |
| Daily Near-Surface Air Temperature ($^0$C) | SSP585 | 2020-2100 | positive |
| Daily Maximum Near-Surface Air Temperature ($^0$C) | Historical | 1981-2020 | positive |
| Daily Maximum Near-Surface Air Temperature ($^0$C) | SSP245 | 2020-2100 | positive |
| Daily Maximum Near-Surface Air Temperature ($^0$C) | SSP585 | 2020-2100 | positive |
| Daily Minimum Near-Surface Air Temperature ($^0$C) | Historical | 1981-2020 | positive |
| Daily Minimum Near-Surface Air Temperature ($^0$C) | SSP245 | 2020-2100 | positive |
| Daily Minimum Near-Surface Air Temperature ($^0$C) | SSP585 | 2020-2100 | positive |
| Precipitation (mm) | Historical | 1981-2020 | negative |
| Precipitation (mm) | SSP245 | 2020-2100 | No Trend |
| Precipitation (mm) | SSP585 | 2020-2100 | negative |
| Daily Maximum Near-Surface Wind Speed (m/s) | Historical | 1981-2020 | No Trend |
| Daily Maximum Near-Surface Wind Speed (m/s) | SSP245 | 2020-2100 | No Trend |
| Daily Maximum Near-Surface Wind Speed (m/s) | SSP585 | 2020-2100 | negative |
| Extreme precipitation / 100-year 24-hour rainfall | SSP245 / SSP585 | Future vs. 1981–2010 baseline | Positive change in intensity, especially under SSP585 |

P Values indicate that most trends are statistically significant ($P < 0.05$) positive trend. Tau values show the strength and direction of the trends. Negative trends are observed in daily mean near-surface wind speed under future scenarios. In contrast, strong positive trends are evident in temperatures across all periods and scenarios. The results highlight the significant changes in climate variables over time, with strong trends expected in future scenarios, particularly temperature increases and changes in extreme precipitation.

## 5.6 Caspian Sea level Fluctuations

The Caspian Sea has experienced substantial historical fluctuations, including both periods of decline and periods of rise. Historic sea level records indicate that the Caspian Sea level declined until the late 1970s, followed by a marked rise from the late 1970s to the 1990s. After this period of increase, the sea level subsequently began to fall again. Therefore, the key issue for long term infrastructure planning is not only sea level rise, but the broader uncertainty associated with Caspian Sea level fluctuations.

Caspian Sea Level Change between 1840-2015 is given in Figure 5-9.

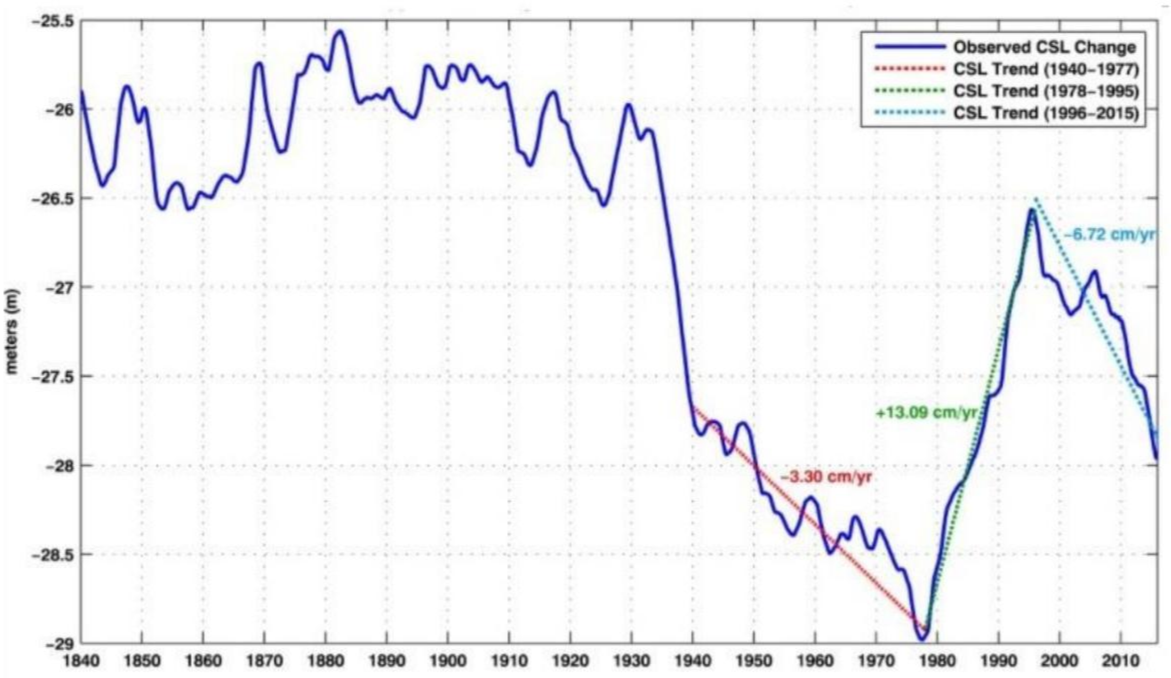


**Figure 5-9 Caspian Sea Level Change 1840-2015**

Future projections of Caspian Sea level remain uncertain and differ across studies. Some studies indicate that increasing evaporation under a warmer climate may lead to further decline of the Caspian Sea level. In this context, the “worsening situation” described by Chen et al. (2017) is understood as a scenario in which the Caspian Sea level continues to retreat, particularly if increased evaporation is not offset by increased river discharge and precipitation. Other studies, however, have suggested possible increases in sea level, highlighting the uncertainty associated with long-term projections.

For the Project, Caspian Sea level fluctuation is therefore treated as a high uncertainty climate related factor rather than a single direction sea level rise hazard. The main potential relevance to the metro infrastructure is through changes in groundwater conditions rather than direct coastal inundation. Given this uncertainty, the Project design should maintain flexibility through groundwater monitoring, drainage performance monitoring, and periodic review of sea level and groundwater conditions during operation.

# 6. Climate Hazard Assessment

Based on the analysis of observed climate conditions and future projections, key climate hazards relevant to the Project have been identified. These hazards are defined based on their potential to affect metro infrastructure, operations, and users.

## 6.1 Heat-Related Hazards

Climate projections indicate a substantial increase in air temperatures across the study area. Mean temperatures are projected to rise by approximately 2–3°C under SSP2-4.5 and 5–6°C under SSP5-8.5 by the end of the century. Maximum temperatures are expected to increase by 4–5°C, while minimum temperatures may increase by up to 6°C, reducing night-time cooling. Possible heat related hazards have been defined as follows:

- Extreme heatwaves
- Thermal Stress on Equipment and Personnel
- Increased Cooling Demand / Energy Stress

| | |
|---|---|
| Sensitivity | • Increasing temperatures may cause thermal stress on metro infrastructure, potentially affecting the performance of rail systems, electromechanical equipment, and signalling systems.<br>• Higher temperatures may also lead to increased energy demand due to greater cooling and ventilation requirements within stations.<br>• This increase in night-time temperatures may intensify urban heat island effects, particularly in densely built urban areas, by increasing heat accumulation.<br>• It may also lead to deterioration of thermal comfort conditions in underground stations and tunnels, while increasing the operational load on mechanical ventilation and cooling systems. |
| Climate Risk | These changes indicate a clear intensification of heat-related hazards, including:<br>• Increased frequency and duration of heatwaves<br>• Elevated thermal stress on infrastructure and systems<br>• Reduced night-time cooling and increased heat accumulation |

## 6.2 Flooding and Extreme Rainfall Hazards

Although total annual precipitation does not show a strong trend, projections indicate an increase in short-duration, high-intensity rainfall events.

Extreme value analysis using the GEV distribution shows that:

- 24-hour rainfall associated with a 100-year return period may reach approximately 45 mm

- This corresponds to an increase of approximately 5–10% compared to the historical baseline

Possible flooding and extreme rainfall hazards have been defined as follows:

- Water ingress through station entrances and ventilation shafts
- Overflow from surface drainage systems

| | |
|---|---|
| Sensitivity | • These increases may elevate the risk of flash floods and surface flooding in urban areas by generating large volumes of runoff within short time periods.<br>• In urban environments, intensified rainfall may increase the risks of rapid surface runoff, pluvial flooding, and exceedance of drainage system capacities. For metro projects, these risks represent critical design considerations for tunnels, station entrances, underground infrastructure, and drainage systems.<br>• The intensification of extreme rainfall events may challenge the hydraulic capacity of urban drainage infrastructure, increasing the likelihood of flash floods and urban flooding. This poses a significant design risk particularly for metro entrances, ventilation shafts, and tunnel drainage systems. Therefore, ensuring adequate protection of underground infrastructure against water ingress and designing drainage systems with sufficient capacity is of critical importance. |
| Climate Risks | These changes indicate an intensification of urban flood hazards, particularly in areas where drainage capacity may be exceeded. |

## 6.3 Coastal Hazards (Caspian Sea Level)

Future projections of Caspian Sea level show high uncertainty, with studies indicating both significant decreases and increases. While some studies predict a drop of up to 9 meters in sea level by the end of the century, some models indicate a possible rise of approximately 1.6 meters by 2100. This high level of uncertainty is considered an element that must be carefully addressed in long-term risk assessments for infrastructure systems located in coastal areas. Given this uncertainty, coastal hazards are treated as low-probability but high-uncertainty.

| | |
|---|---|
| Sensitivity | • Increased risk of flooding and groundwater intrusion in metro tunnels and underground stations located near coastal areas (in case of sea level rise).<br>• High uncertainty in sea level projections, requiring greater resilience and flexibility in the long-term planning and design of metro infrastructure. |
| Climate Risks | While no single projection can be considered definitive, fluctuations in sea level may influence:<br>• Groundwater conditions<br>• Coastal drainage systems |

## 6.4 ASHRAE / Design Temperature Stress Test

In order to assess the sensitivity of the ventilation, cooling, environmental control and equipment design assumptions to future climate conditions, an ASHRAE/design stress indicator was developed. The indicator is defined as the annual number of days with daily maximum near-surface air temperature (Tmax) exceeding 35°C.

The baseline period was defined as 1980–2010, while future stress conditions were assessed for 2071–2100 under SSP2-4.5 and SSP5-8.5. Spatial maps were prepared to show the ensemble-median annual number of exceedance days and the change relative to the baseline.

The spatial distribution of the ASHRAE/design stress indicator under SSP5-8.5 is presented in Figure 6-1.

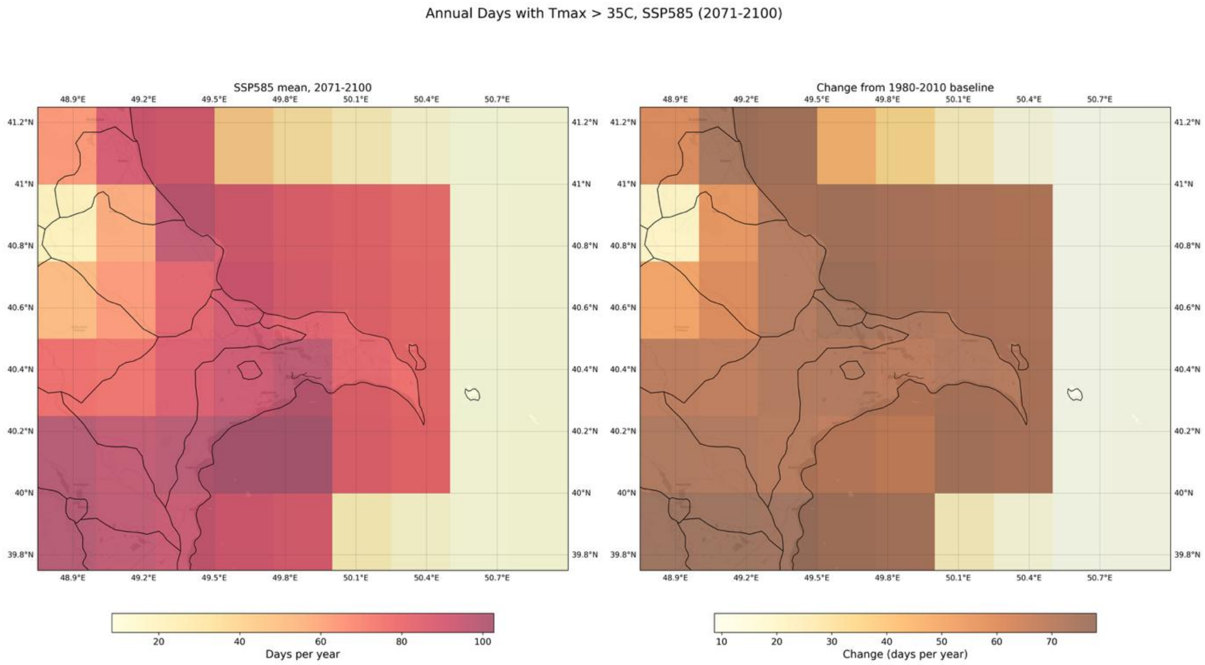


**Figure 6-1 Annual Days with Tmax > 35°C Under SSP5-8.5, 2071–2100 Left: Annual Number of Days Exceeding 35°C. Right: Change in Exceedance Days Relative to the 1980–2010 Baseline)**

The results show that, by 2071–2100, large parts of the Baku area are projected to experience a substantial increase in the annual number of days with Tmax > 35°C. In many inland and urban parts, the number of exceedance days reaches up to 100 days per year, The change map shows that the number of days exceeding 35°C increases markedly compared with the 1980–2010 baseline. Under SSP5-8.5, the increase is generally 60 days of additional hot days per year in Baku City Area.

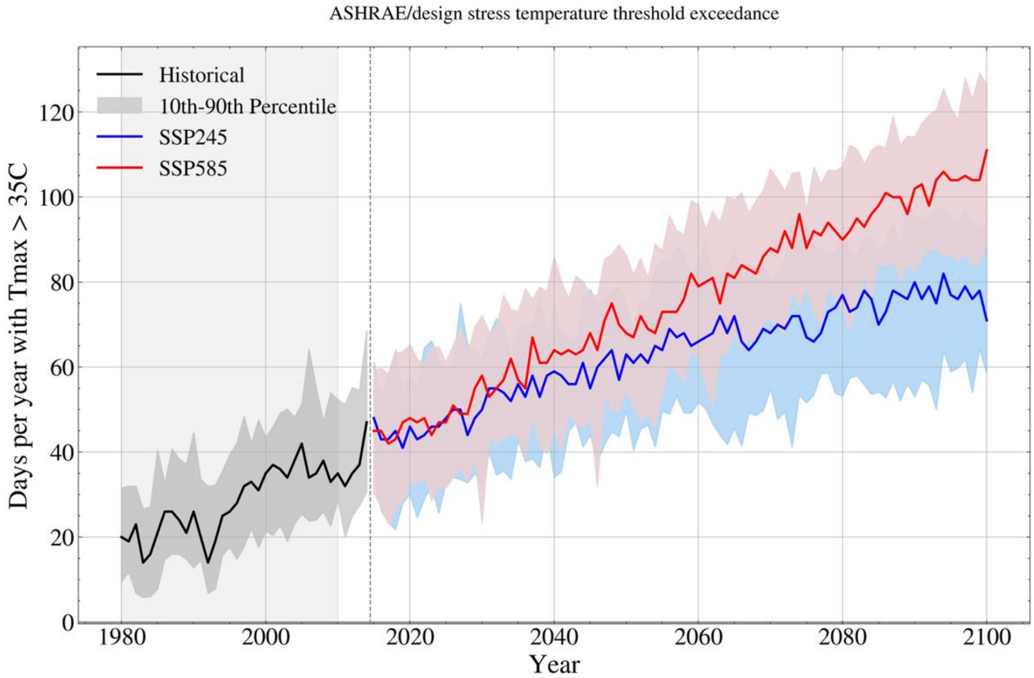


**Figure 6-2 Stress Temperature Threshold Exceedance at the Baku City**

During the historical baseline period of 1980–2010, the average number of days with Tmax > 35°C is approximately 27.8 days per year. This increases to approximately 74.4 days per year under SSP2-4.5 and 97.5 days per year under SSP5-8.5 for the 2071–2100 period. Therefore, compared with the historical baseline, the design point is projected to experience an additional 46.6 days per year above 35°C under SSP2-4.5 and an additional 69.8 days per year under SSP5-8.5.

**Table 6-1 Comparison of Annual Days with Tmax > 35°C by Periods**

| Indicator | Historical 1980–2010 | SSP2-4.5 2071–2100 | SSP5-8.5 2071–2100 |
|---|---|---|---|
| Annual days with Tmax > 35°C | 27.8 days/year | 74.4 days/year | 97.5 days/year |
| Change from historical baseline | — | +46.6 days/year | +69.8 days/year |

The results indicate that high-temperature conditions relevant to ventilation, cooling and environmental control systems are projected to become substantially more frequent, particularly under the high emission SSP5-8.5 scenario.

In addition to the analysis of mean, maximum and minimum temperature projections, a dedicated heatwave stress-test was undertaken to evaluate the sensitivity of metro systems to prolonged high-temperature conditions. Heatwaves were defined using daily maximum temperature during the summer season, with events identified where daily maximum temperature exceeds the local historical summer threshold for at least three consecutive days. The analysis was performed for heatwave frequency, total heatwave days and maximum heatwave duration.

## 6.5 Compound Risk Scenario

To complement the heatwave and flooding hazard, a spatial synthesis map was developed to identify dominant physical climate-risk hotspots. While the preceding sections present separate outputs for temperature, and precipitation, the synthesis map combines these indicators into a single screening-level spatial classification. The purpose is to provide a clearer geographic interpretation of where different climate stressors are most relevant for metro stations, tunnels, ventilation shafts, emergency exits and associated underground infrastructure.

The analysis presented in this section focuses on the SSP585 scenario for the 2070–2100 period. The maps are based on projected late-century hazard indicators and their changes relative to the historical baseline, normalized to support spatial comparison across the Baku Metro study area.

Two hazard groups were mapped:

- ASHRAE/design heat stress, represented by the increase in annual days with daily maximum temperature above 35°C.
- Extreme precipitation and flood-related exposure, represented by the relative change in the 100-year, 24-hour precipitation depth.

These hazard groups correspond to the main physical mechanisms through which climate change may affect the infrastructure. Each hazard group was converted into a normalized score between 0 and 1 using percentile-based min–max normalization. The 10th and 90th percentiles were calculated across grid cells, and the resulting values were clipped between 0 and 1. A higher value therefore indicates that the corresponding hazard is relatively more important in that location compared with other parts of Baku.

### 6.5.1 ASHRAE/Design Heat Stress Score

The ASHRAE/design heat stress score was derived from the projected increase in annual days with daily maximum temperature above 35°C. This indicator was selected because 35°C is directly relevant to design stress testing for ventilation, cooling, station environmental control.

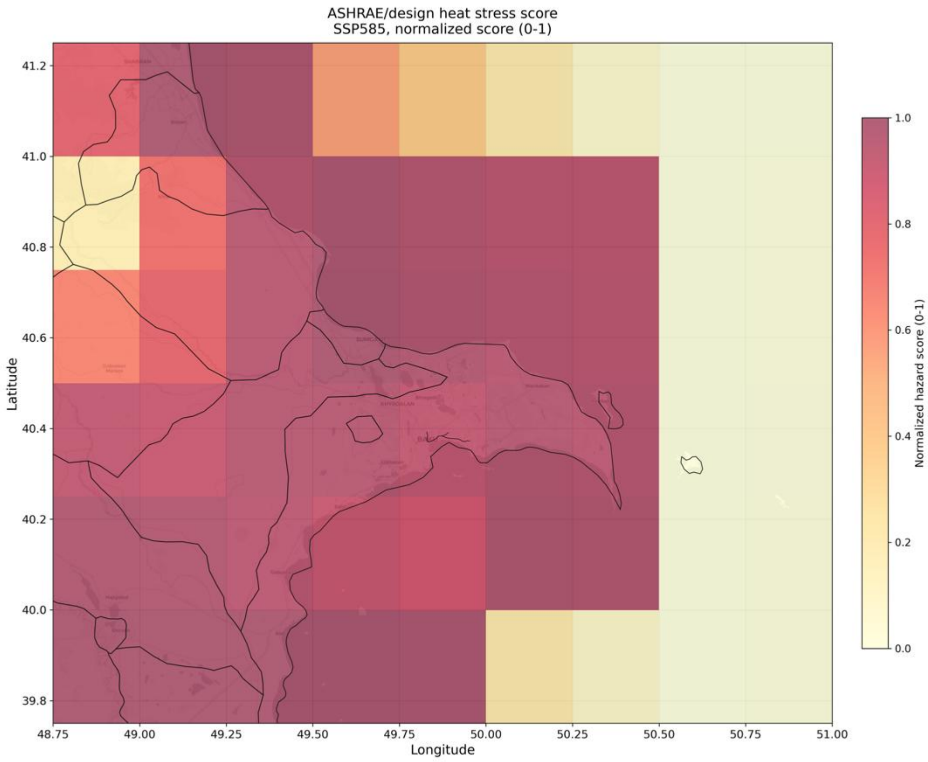


**Figure 6-3 ASHRAE/Design Heat Stress Score under SSP5-8.5 for 2071-2100.**

The heat stress score indicates that temperature related design stress becomes a widespread concern across the Baku Metro study area. Higher scores identify locations where prolonged exposure to high daily maximum temperatures may place greater demand on cooling, ventilation and mechanical systems. These areas should be prioritized for design-margin checks against late-century SSP5-8.5 conditions.

### 6.5.2 Extreme Precipitation and Flood-Related Exposure Score

The extreme precipitation and flood-related exposure score was derived from the projected change in the 100-year, 24-hour precipitation depth. This indicator was selected because short duration extreme rainfall is a key driver of surface runoff and potential water ingress into underground metro assets.

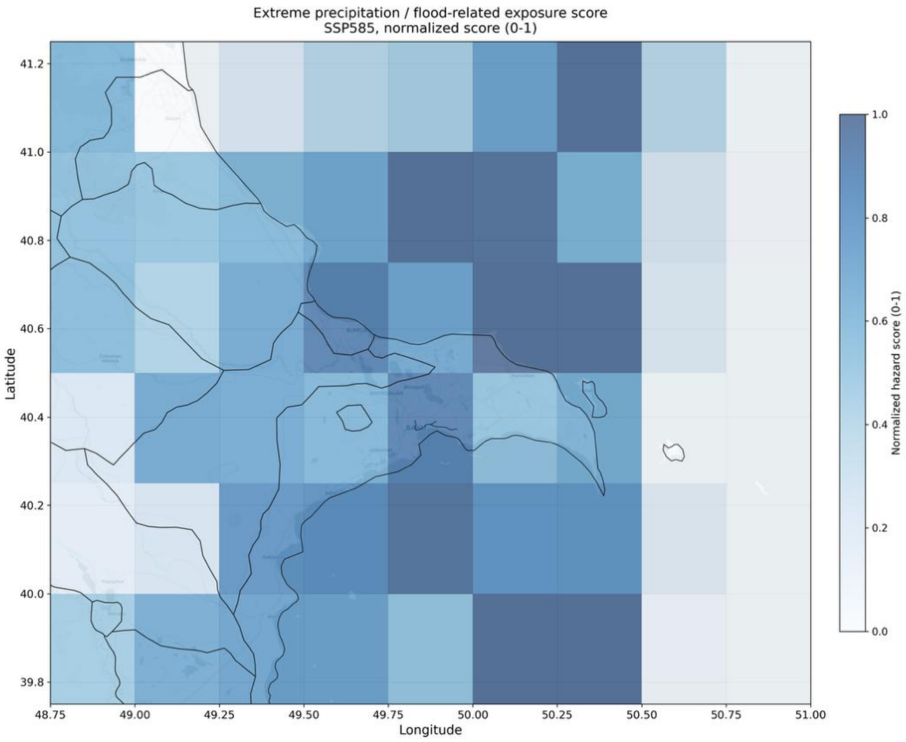


**Figure 6-4 Extreme Precipitation / Flood-Related Exposure Score Under SSP5-8.5 for 2071-2100.**

The score represents the normalized relative change in 100-year, 24-hour precipitation depth. Higher values indicate locations where extreme rainfall intensification is relatively more important within the Baku Metro study area.

### 6.5.1 Compound Risk Areas

Following the individual hazard-score mapping, a dominant climate-risk hotspot map was produced to identify which climate stressor is relatively most important in each grid cell. For each location, the normalized ASHRAE/design heat stress score and the normalized flood-related exposure score were compared, and the hazard with the highest score was assigned as the dominant climate-risk class. A separate compound-risk class was assigned where both hazard scores exceeded the high-risk threshold of 0.66.

The resulting map should be interpreted as a comparative spatial screening product. It identifies which climate stressor is relatively dominant in each location under projected late-century conditions, rather than indicating absolute engineering failure risk. Areas classified as compound hotspots are particularly important because they indicate locations where high-temperature design stress and flood-related exposure may affect metro infrastructure simultaneously.

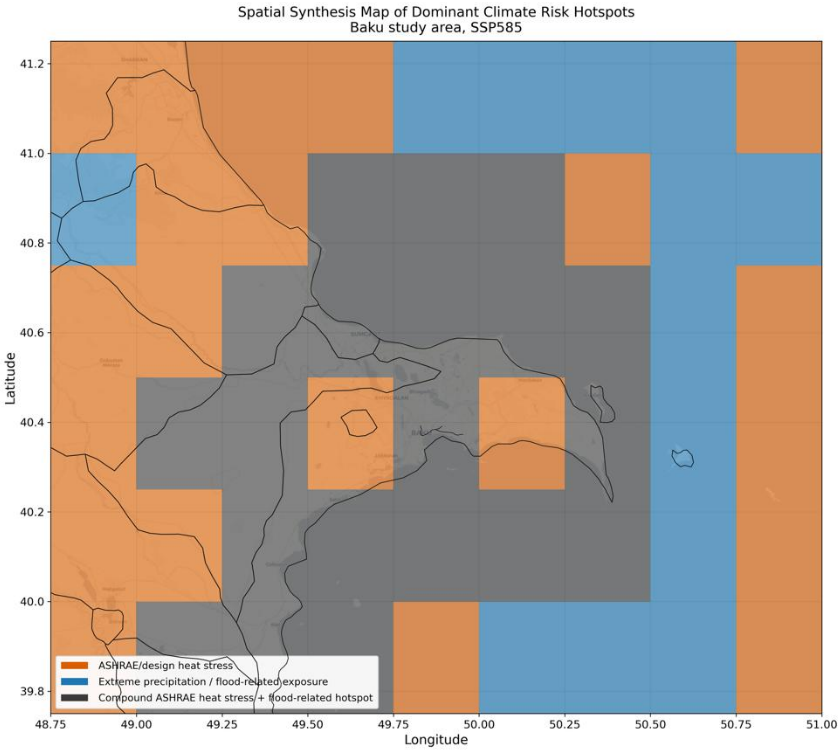


**Figure 6-5 Spatial Synthesis Map of Dominant Climate Risk Hotspots in the Baku Metro Green Line Study Area Under SSP5-8.5.**

Under SSP5-8.5, the synthesis map identifies several grid cells across the Baku Metro study area, including areas around the metro corridor, as compound ASHRAE heat stress and flood-related hotspots. This indicates that late-century climate stress is not limited to a single hazard. These compound-risk zones are especially important because they may involve simultaneous pressures on station environmental control, ventilation systems, electrical systems, drainage, pumping, emergency access and operational continuity. These zones should therefore be considered priority areas for detailed multi-hazard risk assessment, design verification and adaptation planning.

# 7. Climate Risk Assessment

Project supports Azerbaijan's NDC objectives by promoting low-carbon urban mobility and reducing reliance on private vehicle transport. In accordance with MDB Paris Alignment requirements, the Project has undergone climate risk screening and adaptation assessment. Adaptation measures have been developed in proportion to the significance of identified climate risks, with particular focus on extreme heat and extreme rainfall hazards. In addition, Project-related greenhouse gas emissions and emission reduction benefits has been assessed in accordance with applicable MDB GHG methodologies.

The climate risk assessment for the Project is aligned with the AIIB Environmental and Social Framework (ESF) and the AIIB Climate Action Plan (CAP) 2024–2030, which set out the Bank's commitments to mainstreaming climate adaptation and mitigation, Paris Agreement alignment, and climate resilience across its operations. The assessment is further consistent with the climate-related requirements of the AIIB ESF and with the Joint MDB methodology for Paris Agreement alignment. This CRVA operationalises these commitments at the project level by screening climate hazards, assessing materiality and residual risk, and defining adaptation measures consistent with the AIIB climate framework.

This assessment aimed to evaluate the Project's vulnerability to climate change and identify actions that could enhance climate resilience. The assessment was executed in two distinct phases, adhering to the prescribed methodology: (i) climate mitigation and (ii) climate adaptation. Through this structured approach, the assessment provided a thorough analysis of the climate impact and outlined necessary measures to ensure its sustainability in the face of climate change.

## 7.1 Climate Risk Governance and Responsibilities

Effective climate risk management requires clear governance arrangements, defined responsibilities, and reporting mechanisms to ensure that identified climate risks and adaptation measures are systematically implemented, monitored, and updated throughout the Project lifecycle.

The Project will utilize the existing Environmental, Social, Health and Safety (ESHS) management structure to oversee climate risk management. Overall accountability for climate risk management will rest with Baku Metro's ESHS Manager within the PIU. The ESHS Manager will be supported by the Environmental Specialist and will coordinate with the Engineer and Contractor to ensure implementation of climate adaptation measures identified through CRVA.

The Engineer will be responsible for verifying the incorporation of climate-resilient design measures and monitoring their implementation during construction. The Contractor will be responsible for implementing climate-related mitigation, adaptation and emergency response measures and for reporting climate-related incidents and emerging risks through the Project's ESHS reporting system.

Climate risks and adaptation actions will be monitored and reported through the existing Project governance arrangements established under the ESMP and ESAP, ensuring clear accountability and traceability of climate risk management throughout the Project lifecycle.

## 7.2 Climate Change Adaptation

Climate adaptation of the Project was assessed based on the PA methodology, ensuring that the Project aligns with climate goals. By focusing on climate adaptation, the evaluation will identify legislative background, existing and projected climate conditions, possible hazards, key risks, and adaptation measurements. The aim of this assessment is to ensure long-term sustainability of the Project since it is inevitable that the Project will contribute to climate adaptation.

**Assessing the level of climate risks of the Project**

The developed methodology given in Chapter 5 (*Approach to ESIA)* has been adopted as the Climate Risk and Vulnerability Assessment methodology. This methodology is applied to the potential climate hazards output given in Section 6. This comprehensive methodology ensures that each potential hazard is thoroughly evaluated, considering the specific vulnerabilities and exposures associated with the region. The assessment was conducted according to the following criteria, ensuring a detailed and systematic approach to identifying and adapting the possible impacts of climate-related hazards on the Project.

For each climate hazard, its significance is evaluated by defining and evaluating two key aspects:

- The level of the exposure; and
- The vulnerability of the feature or receptor that will be impacted.

**Exposure** essentially describes the intensity of the change that is predicted to occur in the resource/receptor as a result of the impact. The level of exposure tends to reflect a combination of the size of an area that may be affected, the duration over which the aspect may be altered, and the size, degree or scale of that change. In essence, exposure is a descriptor for the degree of change that is predicted to occur in the resource or receptor.

**Sensitivity** refers to the degree to which a system or asset is affected when exposed to a climate hazard. This concept depends on factors such as the physical characteristics of the infrastructure, design standards, operational conditions, and environmental context. High sensitivity indicates that the system may experience significant impacts even under relatively minor climate stressors.

**Adaptive capacity** refers to the ability of a system to adjust to climate change impacts, to moderate potential damages, or to take advantage of opportunities. This capacity is determined by factors such as institutional arrangements, technical expertise, early warning systems, maintenance capabilities, and financial resources. High adaptive capacity enables the system to be more resilient to climate-related stresses and to manage impacts more effectively.

**Vulnerability** is defined as a function of exposure, sensitivity and adaptive capacity. High exposure and high sensitivity, combined with low adaptive capacity, result in high vulnerability; whereas low exposure and/or low sensitivity, combined with high adaptive capacity, lead to lower vulnerability.

In this context, the climate risk level of the Baku Metro has been evaluated in an integrated manner by considering the intensity and frequency of climate hazards (exposure), the response of system components to these hazards (sensitivity), and the capacity to manage these impacts (adaptive capacity).

Accordingly, the relationships used in this assessment can be expressed as follows:

$$Vulnerability = f\,(Exposure, Sensitivity, Adaptive\ Capacity)$$

### 7.2.1 Exposure to Climate Hazards

The Project's exposure to climate hazards which are defined in Section 6 have been assessed. The term exposure encompasses the key characteristics of each projected climate hazard, including its geographic extent, duration, intensity, frequency, and likelihood. The results of the assessment are presented in Table 7-1.

**Table 7-1 Climate Hazards' Exposure Magnitudes**

| Climate Hazard | Exposure Type | Nature of Exposure | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Definition | Geographical Extent (G) | Duration (D) | Intensity (I) | Frequency (F) | Likelihood (L) | Reversibility (R) |
| Increasing Average Temperature & Extreme Heatwaves | Negative/ Direct | | Impacts are expected to occur along the metro corridor and at stations located within the urban project area. | Temperature increases are long-term climatic changes expected throughout the operational life of the metro system. | Increased temperatures may affect operational efficiency and passenger comfort but are expected to remain manageable through engineering controls and system design. | Heatwaves and high temperature events are expected to occur recurrently during summer periods. | | Impacts are reversible through operational adjustments, cooling systems and infrastructure design adaptations. |
| | | Score | Local | Very Long | Medium | Recurrent | | Mid-term |
| | | Value | 2 | 5 | 3 | 3 | - | 3 |
| | Exposure Magnitude (G+D+I+F (or L)) x R | | 39 | | | | | |

| Climate Hazard | Exposure Type | Nature of Exposure | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Definition** | **Geographical Extent (G)** | **Duration (D)** | **Intensity (I)** | **Frequency (F)** | **Likelihood (L)** | **Reversibility (R)** |
| Increase in Extreme Rainfall Events | Negative / Direct | | Potential impacts may affect multiple stations and surrounding urban drainage catchments along the metro corridor. | Impacts may occur throughout the operational life of the project due to long-term climate change. | Extreme rainfall events may temporarily disrupt station access or drainage systems if design capacities are exceeded. | Heavy rainfall events are expected to occur infrequently but repeatedly during extreme weather periods. | | Impacts are generally reversible once rainfall events cease and drainage systems function normally. |
| | | Score | Local | Very Long | High | Infrequent | | Short-term |
| | | Value | 4 | 5 | 4 | 2 | - | 2 |
| | Exposure Magnitude (G+D+I+F (or L)) x R | | 30 | | | | | |
| Changes in Wind Speeds | Negative / Indirect | | Impacts are expected to be limited to localized surface-level structures (e.g., station entrances, ventilation shafts) within the Project area. | Wind-related impacts are short-term and occur only during episodic extreme events. | Impacts are expected to be low, with minor implications for metro infrastructure safety and limited operational or | Extreme wind events are infrequent and episodic in nature. | | |

| Climate Hazard | Exposure Type | Nature of Exposure | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Definition | Geographical Extent (G) | Duration (D) | Intensity (I) | Frequency (F) | Likelihood (L) | Reversibility (R) |
| | | | | | environmental effects. | | | |
| | | Score | Local | Short | Low | Infrequent | | Short-term |
| | | Value | 2 | 2 | 2 | 2 | – | 1 |
| | Exposure Magnitude (G+D+I+F (or L)) x R | | 8 | | | | | |
| Caspian Sea Level Fluctuations | Negative / Indirect | | Potential impacts affected to coastal sections of the urban area where metro infrastructure interacts with groundwater systems. | Changes are long-term processes occurring over several decades. | The impacts are expected to be limited, however the uncertainty associated with their occurrence should be taken into consideration. | Sea level fluctuations occur gradually and continuously over time. | | Impacts are partially reversible depending on long-term hydrological changes. |
| | | Score | Regional | Very Long | Low | Continuous | | Long-term |
| | | Value | 3 | 4 | 1 | 5 | | 2 |
| | Exposure Magnitude (G+D+I+F (or L)) x R | | 26 | | | | | |

### 7.2.2 Vulnerability to Climate Hazards

In addition to characterizing the level of exposure, the other principal step necessary to assign significance is to define the vulnerability of the impacted Project's assets/receptors to the predicted climate hazard. Vulnerability has been assessed by considering both sensitivity and the assest/receptor's adaptive capacity. Sensitivity values are first evaluated and given in Table 7-2. Overall climate risks significances for potential hazards are presented in Table 7-3.

**Table 7-2 Receptor Specific Sensitivity**

| Potential receptor | Sensitivity | | |
|---|---|---|---|
| | Sensitivity Score | Description of the Sensitivity | Sensitivity Value |
| Metro passengers and station users | Medium | Elevated temperatures and heatwaves may cause thermal discomfort and health risks for passengers, particularly vulnerable groups, while increasing stress on metro infrastructure and ventilation systems. | 4 |
| Metro station entrances, ventilation shafts and underground infrastructure | High | Extreme rainfall events may increase surface runoff and temporarily exceed local drainage capacity, potentially leading to water ingress into station entrances and underground structures if not properly managed through drainage systems. | 5 |
| Urban coastal areas and nearby infrastructure systems | Medium | Although sea level fluctuations may influence regional hydrological conditions, the potential impacts on the metro project are expected to remain limited due to the inland location of most stations and the presence of engineered drainage systems. | 3 |

**Table 7-3 Vulnerability Significances**

| Climate hazard | Potential receptor | Exposure | Sensitivity | Adaptive Capacity (E x (S-AC)) | Vulnerability Significance | | |
|---|---|---|---|---|---|---|---|
| | | | | | Value | Score | Description |
| Increasing Average Temperature & Extreme Heatwaves | Metro passengers and station users<br>Metro | 39 | 4 | 2 | 78 | High | Elevated ambient temperatures and heatwave conditions may lead to thermal discomfort and potential health risks for passengers and station users, particularly during peak summer periods. The performance of various components of metro infrastructure—such as rail systems, electromechanical equipment, and signalling systems—is sensitive to temperature variations. As temperatures increase, the operational load on ventilation systems responsible for maintaining thermal comfort also rises. Thermal stress in metro environments, which are used by individuals from all segments of society, poses heightened risks for vulnerable groups such as the elderly, persons with disabilities, and women with children.<br>Without additional climate-resilient design and operational measures, the enclosed station environment and operational management is considered to be low to moderate based on the adaptive capacity, as the absence of passive cooling leads to heat accumulation in underground environments. |
| Increase in Extreme Rainfall Events | Metro station entrances, ventilation shafts and underground infrastructure | 30 | 5 | 2 | 90 | High | Intense rainfall events may lead to temporary water accumulation at station entrances and critical infrastructure elements such as ventilation shafts. While drainage systems are designed to manage stormwater, extreme events may exceed design capacity and cause localized operational disruptions. |
| Changes in Wind Speeds | Metro ground structures | 8 | 1 | 2 | 8 | Low | Climate projections do not indicate a significant long-term increase in wind speeds, and potential impacts are limited due to the predominantly |

| Climate hazard | Potential receptor | Exposure | Sensitivity | Adaptive Capacity (E x (S-AC)) | Vulnerability Significance | | |
|---|---|---|---|---|---|---|---|
| | | | | | Value | Score | Description |
| | | | | | | | underground nature of the metro system and the minor operational implications of episodic extreme wind events. |
| Caspian Sea Level Fluctuations | Urban coastal areas and nearby infrastructure systems | 26 | 3 | 1 | 52 | Medium | Fluctuation in the Caspian Sea level may influence groundwater conditions and urban drainage dynamics in coastal areas. Given the limited direct interaction between the metro infrastructure and coastal processes, the overall sensitivity of the receptor remains not high. |

Wind-related hazards have been identified as not applicable or unlikely to affect the Project and are therefore screened out of further assessment. Under the SSP2-4.5 scenario, an average wind speed decrease of approximately −0.1 m/s is projected, while under the SSP5-8.5 scenario, a decrease of approximately −0.2 m/s is projected. This is mainly due to the predominantly underground nature of the metro system, which limits exposure to wind, and the absence of significant elevated structures. In addition, no strong long-term increase in wind speeds is projected, further reducing the relevance of this hazard for the Project.

Nevertheless, it should be noted that, based on consultations with the Design Engineer, the facility has been evaluated under the 'Terrain Type A' classification, which represents the most severe topographical exposure conditions. A high total wind load of 1.28 kN/m², encompassing mean pressure and instantaneous turbulence effects, was integrated into the structural model in accordance with the AzDTN-2.1-1 standard. Regional wind pressure and suction forces specific to the double-pitched structure were calculated not only for the facades but also for the roof systems. In addition to these, the load was increased by 50% to ensure structural durability. These stringent engineering criteria guarantee the long-term operational reliability and structural integrity of the station and facility buildings against climate change-induced meteorological anomalies, such as increased storm intensities, seasonal extremes, and sudden temperature fluctuations.

As presented in Table 7-3, among the climate hazards assessed for the project, increasing average temperature & extreme heatwaves, increase in extreme rainfall events, and caspian sea level fluctuations were evaluated as having high, high, and medium significance, respectively. Based on these findings, the asset-specific vulnerability of metro structures to the identified climate hazards has been assessed and is presented in the table below.

**Table 7-4 Hazard Asset Specific Vulnerability Matrix**

| Metro structure assets | Increasing Average Temperature & Extreme Heatwaves | Increase in Extreme Rainfall Events | Caspian Sea Level Fluctuations | Description |
|---|---|---|---|---|
| Tunnels | High (5) | High (5) | Medium (3) | Underground environment creates high exposure to heat accumulation and water ingress, making tunnels the most vulnerable asset type. |
| Stations | High (5) | High (5) | Medium (3) | Directly affected by passenger thermal comfort requirements and flood risks at entrances, ventilation shafts, and underground spaces. |
| Rolling stock | High (5) | Low (1) | Low (1) | Sensitive to elevated temperatures affecting HVAC and equipment performance, but less exposed to flooding. |
| Signaling | High (5) | Medium (3) | Low (1) | Electronic systems are sensitive to heat and moisture and are critical for operational reliability. |
| Traction power | High (5) | Medium (3) | Low (1) | Elevated temperatures and localized flooding may affect substations and electrical equipment performance. |
| *Numerical values: Low = 1, Medium = 3, High = 5* | | | | |

# 8. Adaptation Measures

According to climate analysis undertaken, it is considered that BMEP has potential increasingly vulnerable to climate change-related risks including flooding, increasing average temperatures and extreme heat, and sea-level fluctuations. This section outlines adaptation measures that address these vulnerabilities during planning, design, construction, and operation of metro systems.

The hazard-specific vulnerability assessments and proposed adaptation measures for priority risks are summarized in the following tables below. The measures have been integrating in the design of metro systems in order to ensure that design standards are adapted to possible climate change effects.

## 8.1 Increasing Average Temperature & Extreme Heatwaves

As defined in Section 13.5, Baku currently experiences average summer temperatures of 27–30°C in July–August and average winter temperatures of 3–4°C. However, the climate projections presented in Section 13.6 indicate a significant warming trend across the region. By the end of the century, mean temperatures are projected to increase by approximately 2–3°C under SSP2-4.5 and 5–6°C under SSP5-8.5. Annual mean temperatures are expected to reach approximately 20–23°C, while projected maximum temperatures in central and southern parts of Baku may reach 30–32°C. In addition, yearly mean daily maximum temperatures are projected to increase by 4–5°C.

***Design temperatures and mechanical specification***

In the scope of mechanical design in the project, the winter design temperature for the system has been adopted as –2.1 °C, and the summer design temperature has been defined as 35.5 °C based on ASHRAE Climatic Design Conditions. These values are used as the basis for the design of ventilation, cooling, and environmental control systems within stations and tunnels.

Furthermore, equipment durability, operational endurance, and energy performance requirements have been defined within the technical specifications to ensure reliable system performance under elevated temperature conditions. The relevant requirements are outlined in the technical documentation under “CH-5 Environmental Control System”, particularly Sections 5.5.2 (Split, Multi-Split and VRF Systems) and 5.5.4 (Duct Type Fans). These specifications require that installed mechanical equipment, including air-conditioning units, comply with Class A energy efficiency standards, thereby ensuring improved operational efficiency while maintaining adequate cooling performance under higher ambient temperature conditions.

***Operating thresholds of temperature-sensitive systems***

The qualitative asset-sensitivity rating presented in Table 7-4 is supplemented with an assessment of operating temperature thresholds for the three temperature-sensitive operational systems – rolling stock, traction power and signalling. For each system, the governing operating threshold is the controlled internal condition of the equipment room (or, for rolling stock, the platform/tunnel and rail environment). These thresholds are maintained by dedicated mechanical cooling and ventilation, specified to Class A efficiency. The table below sets the design-guaranteed internal condition and installed cooling capacity for Station B5.

The internal design conditions for all signalling and traction-power equipment rooms are decoupled from outdoor temperature by dedicated, Class A mechanical cooling, with setpoints (22–30°C) well below equipment failure ranges.

**Table 8-1 Operating Threshold Assessment**

| System / asset | Supporting room – setpoint / installed cooling | Design-guaranteed internal condition |
|---|---|---|
| **Signalling** | Signalling Room – 22°C / 50% RH; 5,600 W cooling | Held at 22°C / 50% RH by dedicated cooling |
| **Signalling (comms)** | Communication Room – 22°C / 50%; 3,900 W. GSM Room – 22°C / 50%; 2,600 W. Telecom Equipment Room – 22°C / 50%; 2,400 W | Held at 22°C / 50% RH |
| **Signalling (power back-up)** | Battery Room (UPS) – 22°C / 50%; 6,800 W | Held at 22°C / 50% RH |
| **Traction power** | Traction Power Room – 30°C / 50%; 53,600 W cooling; 16,150 m³/h | Held at 30°C / 50% RH |
| **Traction power (MV/DC)** | MV & DC Equipment Room – 25°C / 50%; 26,600 W; 16,000 m³/h | Held at 25°C / 50% RH |
| **Traction power (LV)** | LV Equipment Room – 25°C / 50%; 12,600 W; 7,600 m³/h | Held at 25°C / 50% RH |
| **Traction power (transformer)** | Transformer Room – 30°C / 50%; 34,700 W; 10,450 m³/h | Held at 30°C / 50% RH |
| **Traction power (battery)** | Battery Room – 22°C / 50%; 7,100 W | Held at 22°C / 50% RH |
| **Rolling stock** | Rolling stock is not associated with a fixed indoor environment and is primarily influenced by platform, tunnel and rail temperatures. The station design provides a platform ventilation supply capacity of approximately 29,550 m³/h, which contributes to maintaining acceptable thermal conditions within operational areas. | |

The proposed measures are generally adequate to address heat-related risks, as the adoption of ASHRAE-based design temperatures and high-efficiency mechanical systems provides a solid basis for maintaining performance under increased temperatures.

***Design margin and sensitivity***

To stress-test the adopted design temperatures against the high-emission scenario, a design-temperature stress indicator was developed (See Section 6.1), , defined as the annual number of days on which daily maximum near-surface air temperature (Tmax) exceeds 35 °C, evaluated for 1980–2010 and 2071–2100 under SSP2-4.5 and SSP5-8.5 using the ensemble median. At the Baku City design point, exceedance days rise from approximately 27.8 per year in the baseline to about 74.4 under SSP2-4.5 and 97.5 under SSP5-8.5 (+46.6 and +69.8 days/year), with large inland and urbanised areas reaching up to around 100 days per year. High-temperature conditions relevant to ventilation, cooling and environmental control systems are therefore projected to become substantially more frequent, particularly under SSP5-8.5.

While the 35.5 °C design value is not exceeded on a mean-of-maxima basis, the upper tail of the maximum-temperature distribution shifts upward by approximately 4–5 °C, implying a climate-adjusted peak design condition of the order of 39–40 °C by end-century. The 35.5 °C value therefore remains consistent with the service life of the first generation of mechanical equipment (≈ 25–30 years, to the

2050s) but is expected to be exceeded more frequently over the 100-year civil design life. Since equipment-room conditions are decoupled from the outdoor climate by dedicated Class A cooling, the governing future vulnerability is the capacity of the heat-rejection plant (chillers and condensers) at elevated outdoor temperatures rather than the internal setpoints themselves.

Adequate margin is therefore retained for the installed equipment generation, provided that;

(i) physical, electrical and structural provision is made for staged augmentation of cooling capacity at equipment-replacement cycles; and

(ii) the adopted design dry-bulb is reviewed against an updated, climate-adjusted ASHRAE condition at each major refurbishment.

On this basis, the proposed measures are considered adequate to address heat-related risks for the installed generation of mechanical equipment. These provisions are reflected in the adaptation measures in Table 8-2 and in the residual-risk monitoring measures in Table 8-7 and Table 8-8.

The heat related hazard vulnerability assessments and additional measures have been considering for the adaptation are summarized in the Table 8-2 with their Technical Design references and estimated costs.

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**Table 8-2 Heat Related Hazard**

| Climate Hazard | Vulnerability | Proposed Measures | Status of Implementation | TD Reference | Estimated CAPEX (USD) |
|---|---|---|---|---|---|
| Increasing average temperatures | Mean temperatures are projected to rise by approximately 2–3°C under SSP2-4.5 and 5–6°C under SSP5-8.5 by the end of the century. Rising temperatures may cause thermal stress on rail, electromechanical, and signalling systems, and deteriorate thermal comfort conditions in underground stations while overloading mechanical systems. | (structural)<br>The Project incorporates climate-responsive design measures, including the adoption of ASHRAE-based design temperatures for ventilation and cooling systems, and the specification of high-efficiency (Class A) mechanical equipment to ensure reliable performance under increased temperature conditions. | Implementation has been agreed subject to modification on the existing design. | Technical Documentation – CH-5 Environmental Control System, Sections 5.5.2 (Split, Multi-Split, VRF) and 5.5.4 (Duct Type Fans) – Appendix 13-A | 2–5 M USD (climate-related design increase, %0.2-0.5 of total CAPEX) |
| Increasing average temperatures | Maximum temperatures are expected to increase by 4–5°C, while minimum temperatures may increase by up to 6°C, reducing night-time cooling. | (Operational)<br>Pre-cooling protocols to be implemented during off-peak and overnight hours to lower station ambient temperatures before morning passenger demand, reducing daytime energy load peaks. | The implementation of this measure will be undertaken by Contractor with defining in tender documents. | | 50–200 thousand USD/year<br>(small portion of the annual operational energy cost) |
| | The 35.5 °C summer design dry-bulb (≈ ASHRAE 0.4% cooling condition) is adequate for the installed equipment generation, but the climate-adjusted peak design | (structural / operational)<br>Cooling-plant and heat-rejection equipment to be specified with explicit capacity headroom for elevated outdoor | Related implementations will be monitored and defined in O&M procedures by BM as outlined in ESAP. | Mechanical Room Schedule (Room Table) – Appendix 13-A | 0.5–2 M USD (Reserve space/electrical/structural allowance at the construction stage, %0,1-0,4 of |

| Climate Hazard | Vulnerability | Proposed Measures | Status of Implementation | TD Reference | Estimated CAPEX (USD) |
|---|---|---|---|---|---|
| | condition is projected to rise up to +4–5 °C by end-century under SSP5-8.5. Equipment-room setpoints remain decoupled from outdoor conditions; the governing future vulnerability is heat-rejection (chiller/condenser) capacity at elevated outdoor temperatures. | design conditions (climate uplift of +2–3 °C mid-century, up to +4–5 °C end-century above the historical ASHRAE value). Physical, electrical and structural provision to be reserved for staged augmentation of cooling capacity at equipment-replacement cycles. | | | Electrical/Mechanical cost)<br>5–15 M USD<br>(in 2050s, Install larger cooling capacity, O&M / lifecycle) |
| | The civil design life (100+ years) exceeds the mechanical equipment design life, so the original design dry-bulb is expected to be exceeded more frequently over time under continued warming. | (operational / lifecycle) The adopted design dry-bulb to be reviewed against an updated, climate-adjusted ASHRAE climatic design condition at each major refurbishment / equipment-replacement cycle, and cooling capacity re-sized accordingly. | To be defined in O&M procedures by Baku Metro. | | 20–60 thousand USD/cycle<br>(Consultancy; O&M item) |
| Extreme heatwaves | Maximum temperatures are expected to increase by 4–5°C, while minimum temperatures may increase by up to 6°C, reducing night-time cooling. This will lead to increased energy demand due to greater cooling and ventilation requirements within stations. | (structural)<br>Station architectural design incorporates passive heat mitigation strategies such as high-performance thermal insulation on tunnel linings and station structures, and optimised station orientation | The implementation of this measure has been discussed with Design Engineer, and its implementation has been agreed subject to modification on the existing design. | CH-5 ECS, Sections 5.5.2 and 5.5.4 | 1–3 M USD<br>(%0.2–0.6 of civil works in CAPEX) |

| Climate Hazard | Vulnerability | Proposed Measures | Status of Implementation | TD Reference | Estimated CAPEX (USD) |
|---|---|---|---|---|---|
| | | and layout to minimise solar heat gain. | | | |
| | | (construction-phase)<br>Contingency and adaptive management responses defined in OHSP (Section 4.28) and CHSP (Section 4.2.4) will be incorporated in EPRP by Contractor. | EPRP will be prepared by Contractor as outlined in ESMP. | | 50–150 thousand USD<br>(Within contractor preliminaries / EPRP) |
| Thermal Stress on Equipment and Personnel | Maximum temperatures are expected to increase by 4–5°C, while minimum temperatures may increase by up to 6°C, reducing night-time cooling. This will increase heat stress risks for workers, raising occupational health and safety concerns. | (operational)<br>Procedures for shutting down works, evacuating workers, securing cranes and materials, and managing public safety around construction zones during extreme events.<br>OHSP requires to develop detailed procedure for occupational heat stress assessment for operational-phase metro workers and passengers. | Related procedures will be prepared by Contractor as outlined in ESMP | | 20–80 thousand USD<br>(Procedure + monitoring equipment)<br>. |

## 8.2 Extreme Rainfall Events and Urban Flood Risk

In the scope of detailed design of the Project, a hydrological and hydraulic assessment has been conducted to evaluate rainfall-induced runoff and potential flooding hazards along the project corridor. The study aimed to ensure that the design of underground infrastructure remains safe and resilient under both current and projected hydrological conditions.

The analysis focused on five stations located along the Green Line (Y14, Y15, Y16, Y17) as well as seven emergency exits (AK08–AK14). The primary objective was to establish reliable design criteria for architectural, structural, and mechanical systems, ensuring that metro station structures and associated facilities are adequately protected against hydrological risks. As part of the assessment, rainfall–runoff processes were simulated using the HEC-HMS hydrological model, which allows for the estimation of surface runoff generated by extreme rainfall events within the project catchments. The resulting flows were subsequently incorporated into hydraulic modelling using the HEC-RAS model to determine potential flood extents and inundation areas in the vicinity of metro infrastructure. These modelling exercises enabled the delineation of flood-prone zones and the estimation of flood depths that could affect metro stations and emergency exits during extreme rainfall events.

Statistical analyses have been carried out to evaluate potential flood depths at metro structures under the 100-year, 24-hour storm event scenario. A 100-year return period storm was selected given that international practice commonly applies 1-in-100-year design events for flood risk assessment of major urban transport infrastructure, particularly where passenger safety and operational continuity are key considerations. The values obtained through profile line evaluations were compiled in the modelling results tables, providing an overview of the potential inundation levels that may occur around specific stations and emergency exit structures.

As defined in Section 5.4, precipitation projections indicate that 24-hour rainfall associated with a 100-year return period may reach approximately 45 mm which corresponds to an increase of approximately 5–10% compared to the historical baseline. To consider the climate projections, the hydrological and hydraulic analyses were re-evaluated by incorporating potential climate change impacts, ensuring that the modelling framework reflects both current climatic conditions and projected future rainfall characteristics. The resulting maximum flood depth values for each structure have been compiled and presented in the Table 8-3 and Table 8-4, providing a clear assessment of inundation risks across the Green Line stations and associated infrastructure.

**Table 8-3 Maximum Flood Depth at Metro Structures of Green Line with Consideration of Climate Change Projections.**

| Station | Structure type | Max Flood Depth (m) *(Initial Designed capacity)* | Additional depth according to projected rainfall (m) | Total Depth (m) *(Final Designed Capacity)* |
|---|---|---|---|---|
| Y14 | Station Entrance-1 | 0,15 | 0,15 | 0,30 |
| | Station Exit-1 | 0,3 | 0,15 | 0,45 |
| | Station Entrance-2 | 0,1 | 0,15 | 0,25 |
| | Station Exit-2 | 0,3 | 0,15 | 0,45 |
| | Underpass-South | 0,25 | 0,23 | 0,48 |

| Station | Structure type | Max Flood Depth (m) *(Initial Designed capacity)* | Additional depth according to projected rainfall (m) | Total Depth (m) *(Final Designed Capacity)* |
|---|---|---|---|---|
| | Fire Exit-East | 0,65 | 0,60 | 1,25 |
| | Fire Exit-West | 0,25 | 0,33 | 0,58 |
| | Elevator Entrance-3 | 0,25 | 0,15 | 0,40 |
| **Y15** | Station Entrance-1 | 0,15 | 0,12 | 0,27 |
| | Station Exit-1 | 0,2 | 0,25 | 0,45 |
| | Station Entrance-2 | 0,5 | 0,15 | 0,65 |
| | Station Exit-2 | 0,3 | 0,15 | 0,45 |
| | Underpass-South | 0,3 | 0,18 | 0,48 |
| | Fire Exit-East | 0,35 | 0,38 | 0,73 |
| | Fire Exit-West | 0,45 | 0,18 | 0,63 |
| | Elevator Entrance-3 | 0,25 | 0,18 | 0,43 |
| **Y16** | Top Left Corner | 0,75 | 0,15 | 0,90 |
| | Top Right Corner | 0,2 | 0,15 | 0,35 |
| | Bottom Left Corner | 1,55 | 0,20 | 1,75 |
| | Bottom Right Corner | 0,25 | 0,27 | 0,52 |
| **Y17** | Station Entrance-1 | 0,65 | 0,85 | 1,50 |
| | Station Exit-1 | 0,65 | 0,85 | 1,50 |
| | Station Entrance-2 | 0,55 | 0,35 | 0,90 |
| | Fire Exit-West | 0,65 | 0,23 | 0,88 |
| | Elevator Entrance-1 | 0,25 | 0,15 | 0,40 |

**Table 8-4 Maximum Flood Depth at Emergency Exit Structures of Green Line with Consideration of Climate Change Projections**

| Emergency Exits | Structure type | Max Flood Depth (m) *(Initial Designed capacity)* | Additional depth according to projected rainfall (m) | Total Depth (m) *(Final Designed Capacity)* |
|---|---|---|---|---|
| Green Line | Ak-08 | 0,45 | 0,19 | 0,64 |
| | Ak-09 | 0,7 | 0,15 | 0,85 |
| | Ak-10 | 0,2 | 0,92 | 1,12 |
| | Ak-11 | 0,6 | 0,14 | 0,74 |
| | Ak-12 | 0,25 | 0,15 | 0,4 |
| | Ak-13 | 0,45 | 0,15 | 0,6 |
| | Ak-14 | 0,6 | 0,23 | 0,83 |

The flooding vulnerability assessments and additional measures have been considering for the adaptation are summarized in the Table 8-5.

**Table 8-5 Flooding and Extreme Rainfall Hazard**

| Climate Hazard | Vulnerability | Proposed Measures | Status of Implementation | Estimated CAPEX (USD) |
|---|---|---|---|---|
| Floods | 24-hour rainfall for a 100-year return period is projected to reach ~45 mm, representing a 5–10% increase compared to historical levels. | (structural) Hydrological and hydraulic modelling (HEC-HMS and HEC-RAS), including climate change-adjusted 100-year storm scenarios, has been incorporated into the design to define flood levels and ensure that metro stations, tunnels, and emergency exits are adequately protected against rainfall-induced flooding and water ingress. | The implementation of this measure has been discussed with Design Engineer, and its implementation has been agreed subject to modification on the existing design. | 50–150k USD (modelling study) 3–8 M USD (additional flood-resilience construction, 0.6–1.5% of civil works) |
| | | (operational) Temporary bunds, cofferdams, diversion channels, sump pumps and back-up power to keep shafts | Operational mitigation measures will be implemented by BM as outlined in ESMP. | 1–3 M USD (0.2–0.6% of civil works) |

| Climate Hazard | Vulnerability | Proposed Measures | Status of Implementation | Estimated CAPEX (USD) |
|---|---|---|---|---|
| | | and station boxes dry during storms. | | |
| | | (construction-phase) Contingency and adaptive management responses defined in OHSP (Section 4.11) and CHSP (Section 4.2.4) will be incorporated in EPRP by Contractor. | EPRP will be prepared by Contractor as outlined in ESAP. | 50–150k USD (Within contractor EPRP) |

## 8.3 Fluctuations in the Caspian Sea Level and Coastal Risks

The sea level fluctuations vulnerability assessments and additional measures have been considering for the adaptation are summarized in the Table 8-6.

**Table 8-6 Sea Level Fluctuations Hazard**

| Climate Hazard | Vulnerability | Proposed Measures | Status of Implementation | TD References | Estimated CAPEX (USD) |
|---|---|---|---|---|---|
| Sea Level Fluctuations | Uncertain long-term fluctuations in the Caspian Sea level, potentially leading to significant changes in coastal and groundwater conditions. | The design incorporates elevation criteria (minimum 15 m above sea level) and accounts for up to 1 m seasonal groundwater level fluctuations, ensuring resilience against sea-level rise and hydrostatic pressure changes. | The implementation of this measure has been discussed with Design Engineer, and its implementation has been agreed subject to modification on the existing design. | Hydrological and Hydraulic Assessment Report (HEC-HMS / HEC-RAS) – Appendix B | 0.5–2 M USD (groundwater tanking/waterproofing uplift) |
| Sea Level Fluctuations | Uncertain long-term fluctuations in the Caspian | (operational) Clear allocation of responsibilities | Contractor to develop EPRP before mobilization and | | 30–100k USD (setup + small annual O&M; EPRP procedural) |

| Climate Hazard | Vulnerability | Proposed Measures | Status of Implementation | TD References | Estimated CAPEX (USD) |
|---|---|---|---|---|---|
| | Sea level, potentially leading to significant changes in coastal and groundwater conditions. | and contingencies related to extreme weather delays, site protection and reinstatement. | consider possible reinstatement related to climate risks as outlined in . | | |
| | | | | | |

## 8.4 Residual Impacts

Table 8-7 and Table 8-8 present the residual impact significances, after mitigation measures are implemented. Tables also define contingency and adaptive management responses.

**Table 8-7 Residual Risk Magnitudes**

| Potential Risk | Impact Type | Nature of Impacts | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Definition | Geographical Extent (G) | Duration (D) | Intensity (I) | Frequency (F) | Likelihood (L) | Reversibility (R) |
| Residual thermal stress on infrastructure & increased energy demand | Negative | Despite ASHRAE design and Class A equipment, extreme end-of-century warming (especially SSP5-8.5) will lead to baseline energy load increases and efficiency drops during peak periods. | | | | | | |
| | | Score | Local | Long | Low | - | Likely | Long-term |
| | | Value | 2 | 4 | 2 | - | 3 | 4 |
| | Exposure Magnitude (G+D+I+F (or L)) x R | | 44 | | | | | |
| Residual flash flood ingress risk due to extreme rainfall events | | Hydraulic modelling protects against 100-year storms, but rainfall exceeding the 45 mm threshold (e.g., a 200-year event) or local drainage failures outside metro jurisdiction could cause minor water ingress. | | | | | | |
| | | Score | Local | Medium | Medium | - | Unlikely | Short/mid-term |
| | | Value | 2 | 3 | 3 | - | 1 | 2 |
| | Exposure Magnitude (G+D+I+F (or L)) x R | | 18 | | | | | |
| Contractual disputes & climate-induced delays | Negative | Clear allocation of responsibilities in tender documents mitigates risks, but unpredictable seasonal delays may still trigger minor legal or financial friction between the Contractor and Client. | | | | | | |
| | | Score | Local | Medium | Low | - | Likely | Short/mid-term |
| | | Value | 1 | 2 | 1 | - | 1 | 2 |
| | Exposure Magnitude (G+D+I+F (or L)) x R | | 10 | | | | | |

**Table 8-8 Residual Risk Significances**

| Potential Impact | Exposure Magnitude | Sensitivity | Adaptive Capacity | Impact Significance | | | Contingency and Adaptive Management Responses |
|---|---|---|---|---|---|---|---|
| | | | | Value | Score | Description | |
| Residual thermal stress on infrastructure & increased energy demand | 44 | 3 | 2 | 44 | Medium | An impact of "**Medium**" significance has an impact magnitude that is within applicable standards but falls somewhere in the range from a threshold below which the impact is minor, up to a level that might be just short of breaching a legal limit. | The performance of mechanical cooling and heat-rejection systems will be monitored periodically (weekly/monthly) during the summer months, including condenser/chiller capacity at elevated outdoor temperatures.<br>During heatwaves, the duration of night-time pre-cooling will be extended.<br>Temperature and humidity sensors within the station will be integrated with the SCADA system to enable real-time monitoring.<br>The adopted design dry-bulb will be reviewed against an updated, climate-adjusted ASHRAE climatic design condition at each major refurbishment / equipment-replacement cycle. |
| Residual flash flood ingress risk due to extreme rainfall events | 18 | 3 | 2 | 18 | Low | An impact of **"Low"** significance is one where a resource/receptor will experience a noticeable effect but probably within applicable standards. | In the event of water flooding the station entrances, the automatic flood gates will be closed. |
| Handling and storage of hazardous | 10 | 2 | 1 | 10 | Negligible | The predicted effect is deemed to be 'imperceptible' or is indistinguishable from natural background variations. | Construction durations must include force majeure delay contingencies, incorporating tolerances for climate-related events. |

| Potential Impact | Exposure Magnitude | Sensitivity | Adaptive Capacity | Impact Significance | | | Contingency and Adaptive Management Responses |
|---|---|---|---|---|---|---|---|
| | | | | Value | Score | Description | |
| materials and waste | | | | | | | Contractor to produce a construction-phase climate risk assessment covering heat and flood schedule risk prior to mobilisation (please refer to the ESAP Actions). Detailed measures to be defined in emergency and response procedures has been presented in OHSP and CHSP. |