# CLIMATE CHANGE RISK ASSESSMENT

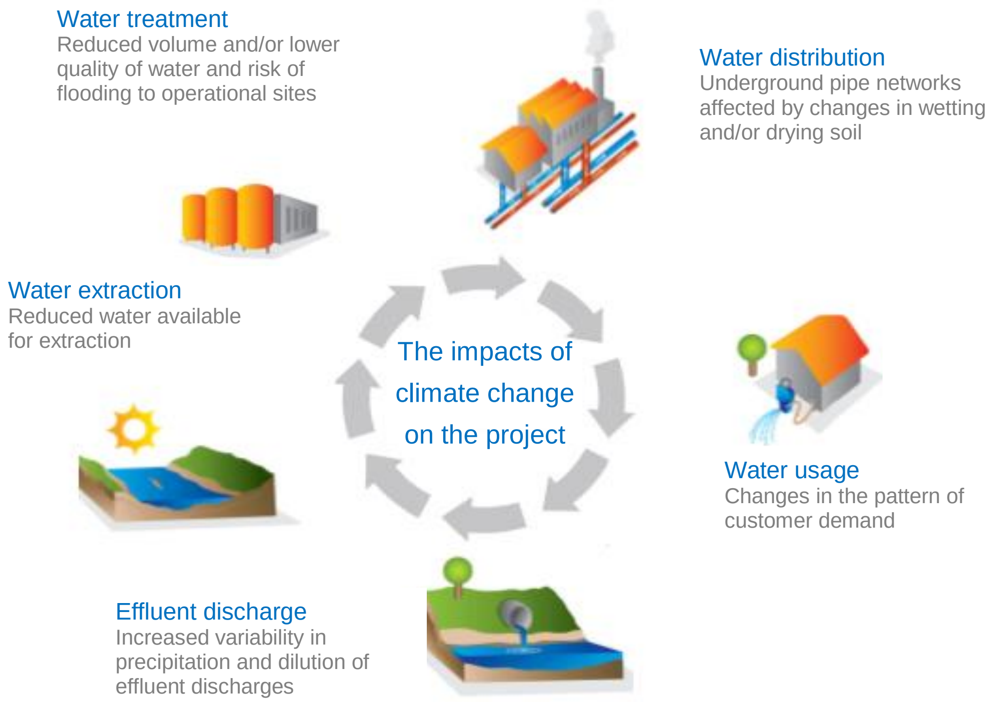
## 1. Introduction

1. The impacts of climate change on water systems in Chaonan District, including water availability, water supply, sewer, and wastewater treatment systems, are expected to be substantial and long-lasting. Climate change impacts that will significantly affect these systems include sea-level rise, higher temperatures, changing precipitation patterns, and increases in the number of droughts and floods. Moreover, severe storms, which currently pose great risks to the system, are expected to increase in intensity in the coming decades.[1] The resulting risks to the area are economic, environmental, physical, social, and fiduciary. Because of the long-lived infrastructure involved, it is important to confront and manage the risks of climate change by prudent early planning, management, and investment decisions.

2. Climate change impacts and risks on the project has been assessed, including the impact of rising sea levels and temperature, increasing extreme weather events, more frequent and intense droughts and floods, changed precipitation patterns, and tropical cyclones on the water system (Figure 1). The climate change risk assessment for this project is aimed at (i) understanding better the vulnerability of this project to current and future climate impacts, (ii) minimizing the risk of significant climate change impacts on the project, and (iii) assessing—using a risk-based approach—what we can put in place now and plan for the future to increase the resilience of the project.

[1] K. Emanuel. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, Vol. 436, pp. 686–688.

**Figure 1: Concept Diagram of Impacts of Climate Change for the Chaonan Project**




Source: Asian Development Bank.

## 2. Background

### 2.1 Location, Water Supply Characteristics, and Project Scope

3. **Location.** Chaonan District, a district of Shantou, Guangdong Province, covers 599.86 square kilometers ($km^2$), with 11 towns and 232 communities (177 old ones). At the end of 2012, its resident population was estimated at 1,328,700, including 200,200 non-agricultural residents and 1,128,500 agricultural ones. The population density is 2,215/$km^2$, 15.3 times of the national average density of 145/$km^2$.

4. **Water resources.** Water resources of Chaonan District total 580 million cubic meters ($m^3$), of which surface runoff are 548 million $m^3$; and ground water are 0.32 million $m^3$. Its annual available water resources per capita reach 450 $m^3$, only 20% of the national average at 2,200 $m^3$; and 26% of the provincial average in Guangdong at 1,700 $m^3$.

5. **Water storage.** There are 143 reservoirs and ponds in the district, with a combined catchment area of 221.6 $km^2$; and total storage capacity of 226 million $m^3$. Three water systems—Jinxi, Longxi, and Qiufeng—are the major drinking water sources in Chaonan. The water storage capacity of the Jinxi reservoir is at 19.6 million $m^3$, the Longxi reservoir at 53.2 million $m^3$, and the Qiufeng reservoir at 58.3 million $m^3$. They have a total catchment area of

116.6 $km^2$, and the water storage capacity of the three water systems is 82% of the total in Chaonan.

6. The Nanshan Flood Diversion Project is a large-scale comprehensive water conservancy project in Chao, and the mean annual runoff volume is about 12.3 million $m^3$. The project will provide additional water resources for agricultural irrigation.

7. **Water demand.** The total amount of water usage in Chaonan District was 258.01 million $m^3$ in 2010, among which the amount of water usage in agriculture was 115.66 million $m^3$, industry at 48.9 million $m^3$, domestic at 80.66 million $m^3$, forestry and environment at 12.79 million $m^3$. The percentage of water usage in agriculture was 44.8%, industry at 19.0%, domestic at 31.3%, and forestry and environment at 5.0%.[2]

8. **Water supply.** Chaonan District has a total of 66 water services, all sourced from reservoirs and supplying 171,000 $m^3$/day, almost fully covering the district, include 6 water plants and 60 simple water supply systems in rural areas. The six water plants are designed to supply 145,000 $m^3$/day, covering 1,065,000 residents. Five towns in Chaoyang District, including Guiyu, Heping, and Tongyu, with a population of about 300,000 also get water from the six plants.

9. In 2010, about 865,000 residents in plain areas relied on the six water plants for water; and 152,800 residents relied on the 60 simple water supply systems in rural areas. By the end of 2010, the registered population of Chaonan District is 1,328,700, with 77% coverage in water supply.

10. According to the East Guangdong Water Supply Plan, the Han River Water Diversion Project is planned in Shantou Municipality. The project will transfer 100,000 $m^3$/day of treated water (36.5 million $m^3$/year) to Chaonan for addressing its water scarcity problem. The project will be completed and start its operation in 2020.

11. **Challenges.** Water demand and supply in Chaonan District are challenged by increasing domestic and industrial water consumption. The current water supply infrastructure cannot meet present and future demand. The three major water supply systems have yet to be connected for efficient water resource allocation. Water pipe coverage is insufficient, and some water pipes laid out by communities in late 1980s or early 1990s are aging.

12. **Project scope.** The Guangdong Chaonan Water Resources Development and Protection Demonstration Project is a multi-disciplinary and cross-cutting project. Government ministries and departments involved in water conservation (reservoir water supply), forestry (water protection forests), municipal water supply (design of water plants and pipes), education (public environment and health awareness), environmental protection (water resource protection), and city administration (recycling of solid waste) are included. Details are listed in Table 1.

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[2] Shantou Water Resource Bureau. 2011. *Shantou Water Resource Bulletin.* Guangdong, Shantou City.

**Table 1: Guangdong Chaonan Water Resources Development and Protection Demonstration Project**

| Output | Subprojects |
|---|---|
| 1. Improved water resources protection | A1. Public awareness and learning on environment and sanitation<br>A1.1. Training of school teachers and students<br>A1.2. Development of education and training materials<br>A1.3. Establishment of an exhibition hall<br>A1.4. Field trips and social survey<br>A1.5. Propaganda at schools<br>A1.6. Public participation<br>A2. Water conservation reforestation in the catchments of Jinxi, Longxi, and Qiufeng reservoirs<br>A3. Study on pollution prevention and control measures in the catchments of Jinxi, Longxi, and Qiufeng reservoirs[a]<br>A3.1. Pollution source survey and control technology<br>A3.2. Nonpoint source pollution prevention<br>A3.3. Wastewater collection and treatment technology<br>A4. Solid waste collection and treatment in Chengpo and Qiufeng villages |
| 2. Improved water supply infrastructure | B1. Expansion of Qiufeng water supply plant (WSP) by 72,000 cubic meters ($m^3$) per day<br>B2. Rehabilitation of the Jinxi WSP<br>B3. Construction of the Longxi WSP with capacity of 100,000 $m^3$/day<br>B4. Installation of water delivery and distribution pipelines with a total length of about 1,000 kilometers<br>B5. Establishment of a water quality monitoring center<br>B6. Installation of water meters<br>B7. Provision of operation and maintenance equipment |
| 3. Strengthened institutional and staff capacity | C1. Provision of project implementation consulting services,and training includingstudy tours<br>C2. Support for the establishment of a water supply control center<br>C3. Support for the establishment of a water resources management and three-prevention (flood, drought, and typhoon) management center<br>C4. Development of a water resources protection and development action plan<br>C5. Establishment of a project monitoring and evaluation system |

[a] In the government approved project feasibility study report, this subproject was replaced to the Output 3.
Source: Asian Development Bank estimates.

## 2.2 Climatic and Hydrological Characteristics[3]

13. Chaonan District has a humid subtropical climate in South Asia. The maritime climate features warm weather (no hot summers or cold winters), sufficient sunshine and precipitation, and green vegetation all the year.

14. **Temperature.** The average temperature is 21.6°C, and there is a narrow temperature range annually. Historical figures show the temperature reaches the average low level at 13.8°C in January or February, and the highest level at 28.2°C in July or August.

[3] These data were from the Guangdong Climate Center, Guangdong Meteorological Bureau.

15. **Precipitation.** The mean annual precipitation in Chaonan District is about 1,710 millimeters (mm). The distribution of monthly precipitation is uneven, with precipitation from October to March only 8%–22% of annual precipitation (referred to as the drought season); while about 78%–92% of annual precipitation occurs from April to September (referred to as the flood season).

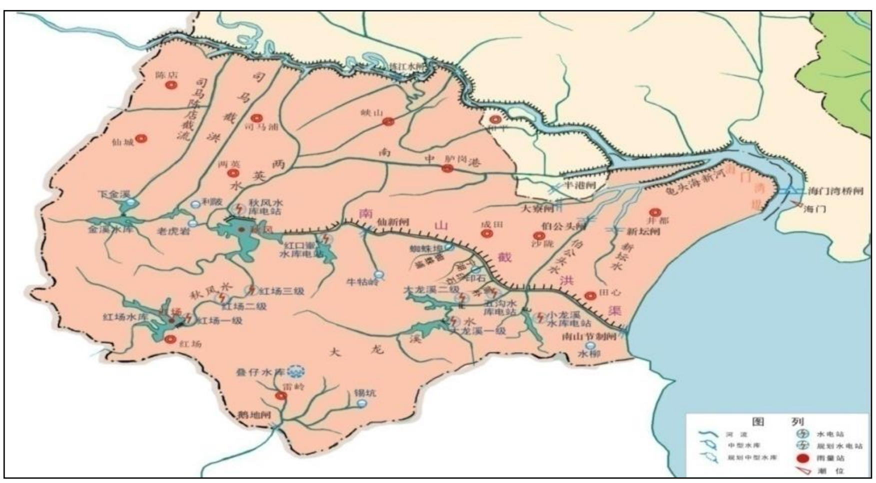
16. **Runoff.** The mean annual depth of runoff is about 800–1,200 mm. The runoff rate is about 0.5–0.6 in Chaonan District. The runoff flows into the South Ocean at last. The mean monthly distribution of runoff is uneven in a year, and the total runoff amount from April to September accounts for 82.2% of the mean annual runoff. The annual variation of runoff is about 0.34–0.40.

17. **Others.** The annual wind velocity in Chaonan District averages 3.5 meters per second (m/s), with the maximum instantaneous wind velocity reaching 47.0 m/s in the northeastern direction. Each year, days with severe convection weathers average 48.8 m/s, with the maximum reaching 59.0 m/s.

### 2.3 Available Water Resources[4]

18. **Rivers.** The Leiling River and Lian River are the main rivers in Chaonan District. The total length of Leiling River is 26 kilometers (km [9.5 km located in Chaonan]) with a catchment area of 444 $km^2$. The catchment area in Chaonan is 61 $km^2$, which accounts for 13.7% of the total catchment area. The Lian River has a length of 94.5 km (41.3 km located in Chaonan), with a catchment area of 1,353 $km^2$. The catchment area in Chaonan is 838.5 $km^2$, which accounts for 62% of total catchment area. The distribution of the water system in Chaonan District is shown in Figure 2 below.

**Figure 2: Water Systems in Chaonan District**




Source: Project feasibility study report.

4 Shantou Water Resources Bureau. 2012. *Shantou City Water Resource Report*. Shantou.

19. **Groundwater resource.** Due to high fluorine content, groundwater resources are not suitable for domestic water use and production use in some places in the district. Chaonan District depends primarily on the water stored in reservoirs and ponds.

20. **Reservoirs.** There are 143 reservoirs and ponds in the district, with a combined catchment area of 221.6 $km^2$; and total storage capacity of 226 million $m^3$. Seven are large- and medium-sized reservoirs with total catchment areas of 163.6 $km^2$; and total storage capacity of 188.0 million $m^3$. Sixty-five are small-sized reservoirs, with a total catchment area of 50.3 $km^2$; and total storage capacity of 36.0 million $m^3$. The remaining 71 are ponds, with a total catchment area of 8.9 $km^2$; and total storage capacity of 2.5 million $m^3$.

21. A number of reservoirs with low water storage capacity are scattered, so they are currently managed by townships or villages and are used for rural domestic water and/or agriculture irrigation.

22. **Nanshan flood diversion project.** Some water is also made available through this large-sized comprehensive water project. The project prioritizes flood diversion and drainage, with a secondary focus on providing water for irrigation, waterways, and drinking water.

23. Completed in 1976, the project is located in the south of the district, on the right bank of the Lian River. It starts from the flood release tunnel in the west of the Jinxi reservoir; passes the Lipo reservoir in the east; collects the water into the Qiufeng reservoir; and collects water from sub-water systems of the Hongkoushe reservoir, the Longxi reservoir, and the Xiaolongxi River; and then, enters the South China Sea in the end. The Nanshan Flood Diversion Project has a total catchment area of 216.6 $km^2$.

## 3. Historical Climate Trends and Impacts

### 3.1 Datasets and Methods

24. **Climate datasets.** There are 52 years daily, monthly and annual climate data from 1961–2012 for Chaoyang climate station which is the nearest climate station with long term records in Guangdong Province. The variables collected include daily precipitation, mean temperature, maximum and minimum temperature, and wind speed.[5] The records about landfall tropical cyclones in Guangdong from 1961–2012 were collected.[6]

25. Mean annual temperature, annual precipitation, and the distribution of seasonal precipitation for 1961–2012 were calculated based on the datasets. Averages for the 1981–2010 time period are provided in some figures as an indicator of more recent trends. A drought index was calculated based on the number of days of rainfall and the area affected (referred to as the

[5] These data were from the Guangdong Climate Center, Guangdong Meteorological Bureau.
[6] These data were from the National Climate Center, China Meteorological Administration.

composite index “CI” of the meteorological drought).[7] Cold days (daily mean temperature less than 5°C) and heat waves (daily mean temperature more than 35°C) were also calculated. All analyses regarding extreme events are based on the Climate Disasters and Impacts Assessment System of the National Climate Center, Meteorological Administration of the People’s Republic of China (PRC).

26. **Hydrological datasets.** There are 30–33 years monthly runoff data from 1979 to 2011 for the six reservoirs. The reservoirs were separated into three river systems and three water supply areas, which are Jinxi river system and water supply area, Longxi river system and water supply area, and Qiufeng river system and water supply area in the proposed project area. The hydrological data available for each water system are shown in Table 2 below.

**Table 2: Hydrology Data for Three Major Water Systems**

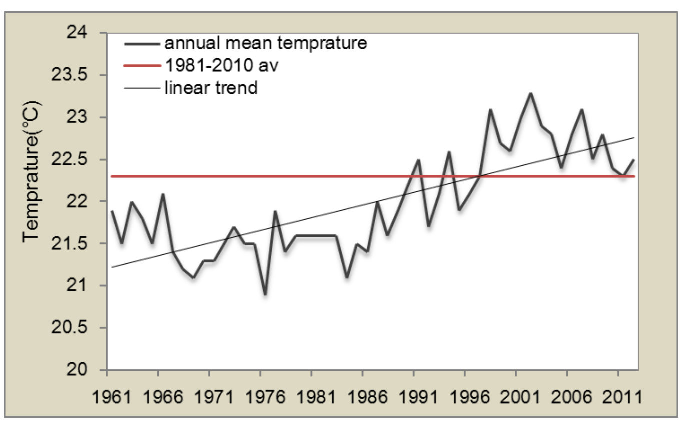
| Reservoirs | Water System | Hydrology Data | Available Data Series | Selected Data Series |
|---|---|---|---|---|
| Upper Jinxi Reservoir | Jinxi | Monthly precipitation;<br>Monthly inflow<br>Monthly outflow | 1982–2011 | 1982–2011 |
| Qiufeng Reservoir<br>Hongchang Reservoir | Qiufeng | | 1980–2011<br>1979–2011 | 1979–2011 |
| Longxi First-cascade Reservoir<br>Longxi Second-cascade Reservoir<br>Xiaolongxi Reservoir | Longxi | | 1979–2011<br>1979–2011<br>1982–2011 | 1982–2011 |

Source: Project feasibility study report.

### 3.2 Historical Climate Trends

27. **The annual mean temperature has increased, especially since the mid-1980s.** Temperature has risen at an average rate of 0.27°C/10a between 1959 and 2012 (Figure 3). Most of this increase occurred post late-1980s.

**Figure 3: Annual Mean Temprature for Chaonan District during 1961–2012** (°C)



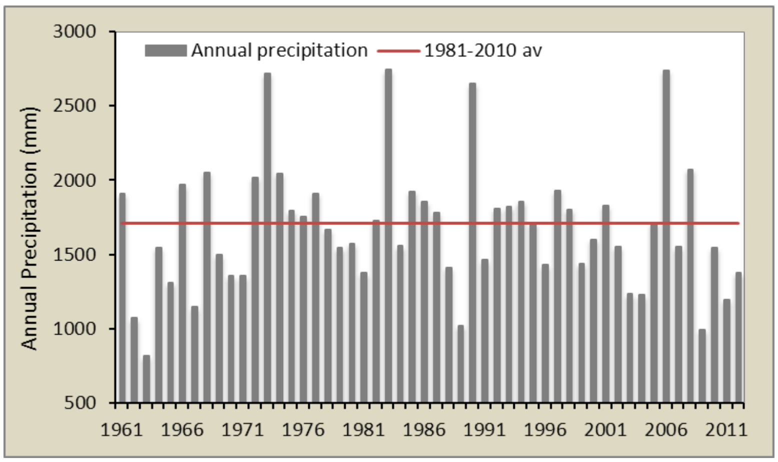

Source: Guangdong and Shantou Meteorological Bureaus.

[7] These data were from the PRC’s Classification of Meteorological Drought Standard (GB/T20481-2006).

28. **Total annual precipitation varies widely.** Between 1961 and 2012, the annual precipitation ranged from 812.3 mm (1963) to 2,740.0 mm (1983). The average annual precipitation has dropped by 19.4 mm/10a. In terms of seasonal distribution, most precipitation occurs in summer and spring.

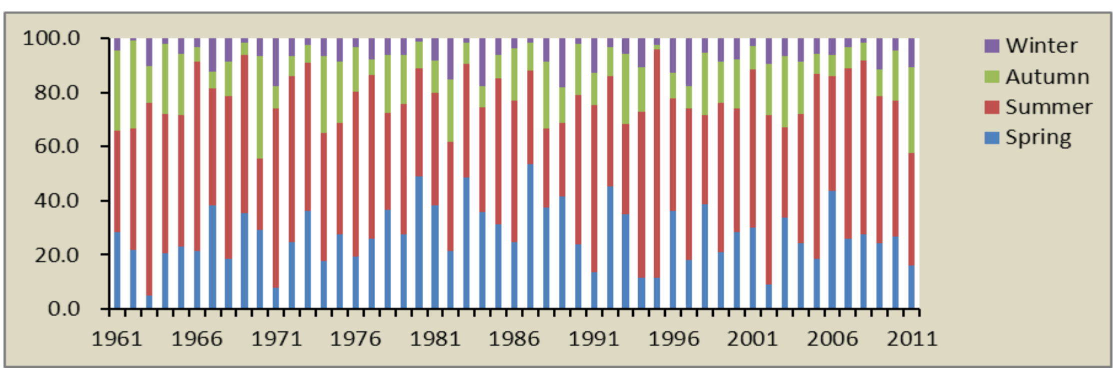
29. **Runoff changes.** The depth (mm) of annual runoff for three reservoirs located in the Chaonan project area from 1979 to 2012 is shown in Figure 6. Average depth fluctuates, with an average depth of approximately 1,000 mm, ranging from a low of approximately 350 mm to a high of approximately 2,350 mm.

**Figure 4: Annual Precipitation for Chaonan during 1961–2012** (millimeter)



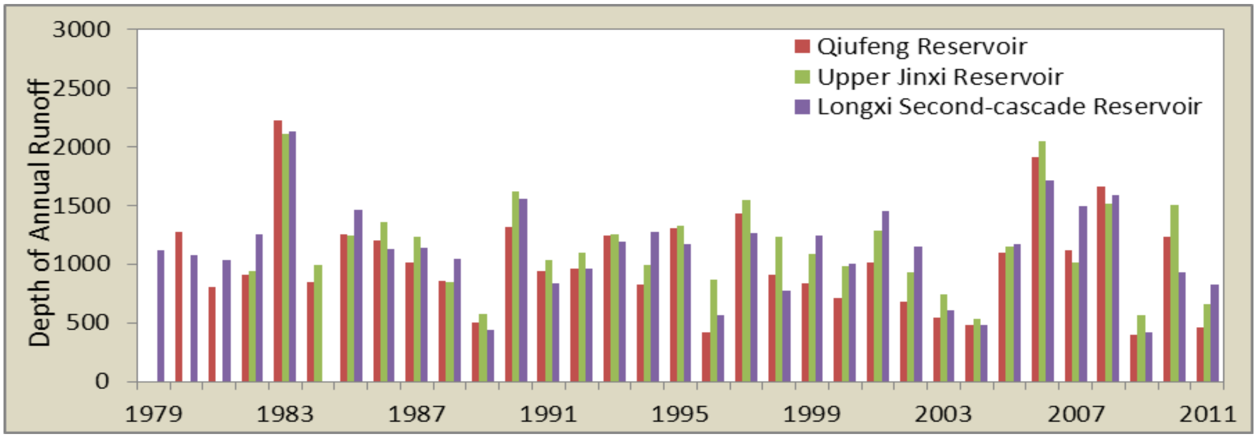

Source: Guangdong and Shantou Meteorological Bureaus.

**Figure 5: Seasonal Precipitation Anomalie for Chaonan during 1961–2012** (%)




Source: Guangdong and Shantou Meteorological Bureaus.

**Figure 6: Depth of Annual Runoff for Three Reservoirs in Chaonan Project during 1979–2012**

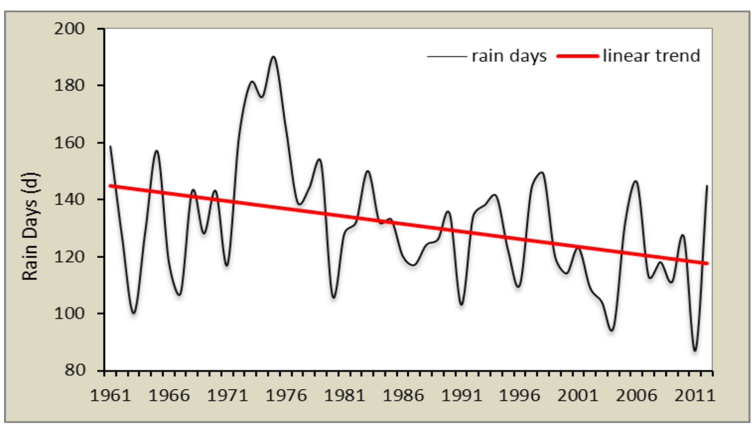



Source: Feasibility study report.

### 3.3 Severe Climate and Climate-Related Disasters

30. Heavy precipitation occurs more often, with more severe impacts from storms and floods. Although observations over the past 50 years indicate no significant rises or drops of the annual mean precipitation, there has been a fall of 4.0 days per decade in terms of the average number of days with precipitation in Guangdong Province (Figure 8). The daily mean precipitation intensity has been increasing by 0.49 mm/day per 10 years, resulting in more frequent heavy precipitation events and a bigger impact of storms and floods (Box 1).

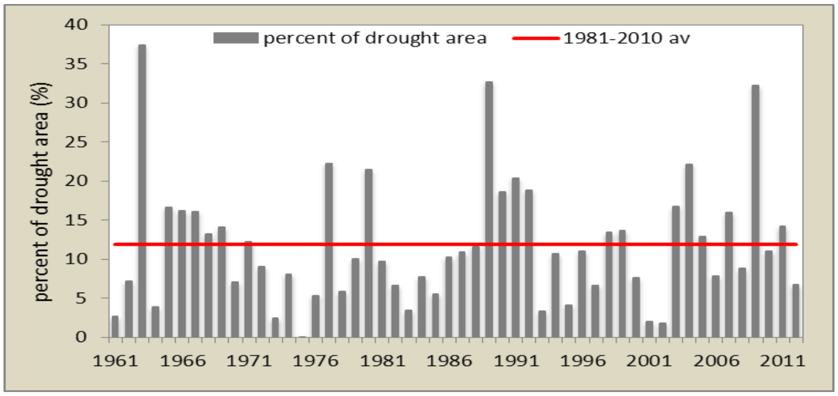
**Figure 7: Number of Annual Days with Precipitation in Chaonan District (1961–2012)**




Source: Guangdong and Shantou Meteorological Bureaus.

31. **More frequent and intense droughts with expanded influence.** Annual precipitation is substantial in Chaonan District, but temporal and spatial distribution changes greatly from year to year, leading to more severe regional and seasonal droughts. Serious droughts occurred in 1963, 1989, 2009, 2010, and 2011 (case study in Box 2 and Figure 8).

**Figure 8: Annual Percent Drought Area in Chaonan District during 1961–2012**




Source: Guangdong and Shantou Meteorological Bureaus.

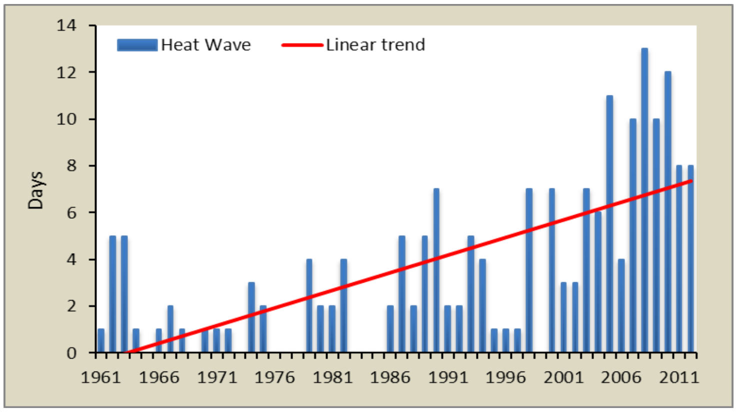
32. **More low-temperature disasters.** The climate in Chaonan District is classified as a tropical and subtropical, and disasters occur when the minimum temperature is less than 5°C. However, extreme low temperature events still occur occasionally (case study in Box 3). From mid-January to early February 2013, snow disasters raged across Guangdong Province with the temperature hitting an historical low. The average temperature was just 9.2°C for 32 days. The low temperature caused broken tree limbs, dead fish, power blackouts, traffic jams, and broken water pipes.

33. **An increase in the frequency of heat waves.** In Chaonan District, the number of days with a minimum temperature of 35°C had been rising by 1.5 day/10a (Figure 9). Heat waves led to undersupply of water and electricity and even severe scarcity of water and electricity if handled improperly. High temperatures have a large impact on domestic and industrial consumption of water and leads to more droughts. Declining crop output and quality potentially undermines food security.

**Box 2: Continuous Droughts in Autumn and Winter in Shantou**

Continuous droughts in autumn and winter in Shantou, 2010/2011 from 1 October 2010 to 28 April 2011, the average precipitation in Guangdong was 225.6 millimeters. In April, the average precipitation was just 39.0 millimeters, hitting a historical low in the same period and 80% less since 1951. On 28 April 2011, the drought reached its peak, covering 98.8% of Guangdong and Shantou. The drought dried up crops, decreased the water level, caused saltwater intrusion in the Pearl River, and led to increased fires in woodlands.

**Figure 9: Changes of Heat Waves in Chaonan District during 1961–2012**




Source: Guangdong and Meteorological Bureaus.

34. **Severe storms and storm surges.** Between 1961 and 2012, a total of 244 severe storms hit Guangdong, with an average of 4.7 severe storms per year. Coastal regions of Guangdong Province are 1.5 times more frequently influenced by storm surges in the past 10 years than previously. Storm surges have been exacerbated by sea-level rise, increasing the probability that waves will surge over buildings in port and threaten the safety and working life of coastal infrastructures (such as docks and embankments).

35. **Sea level.** Since the early 1980s, the mean sea level in the South China Sea, including Guangdong, Guangxi, and Hainan provinces, has risen at a rate of 2.6 mm/a, higher than the global rate (1.8 mm/a). The combination of sea level rise and the increasing intensity of tropical cyclones results are aggravating coastal risk from storm surges.

36. Due to sea-level rise, the tide level has increased, aggravating the salt tide intrusion in the Pearl River Estuary. There have been 9 salt tides in winter since 1989 in the Pearl River Estuary, reaching 10–15 km farther than previously. In addition, this is diminishing the effectiveness of flooding-prevention engineering and port infrastructures, and exacerbating the problems of coastal urban flooding drainage and urban flooding.

## 4. Climate Change Projections and Expected Impacts on Water Resources

### 4.1 Datasets and Methods

37. Datasets of climate change projection used in this report are sourced from the *Climate Change Projection Dataset in [People's Republic of] China* V3.0. The dataset provides the simple ensemble average results in the PRC of multiple scenarios under the Coupled Model Intercomparison Project Phase 5 (CMIP5). The greenhouse gas emission scenario used in the assessment adopts the new Representative Concentration Pathways (RCPs). RCPs are four greenhouse gas concentration trajectories recently adopted by the Intergovernmental Panel on Climate Change used for climate modeling. The RCPs are named based on the possible range

of radiative forcing values (measured in Watt/square meter) in the year 2100. The ensemble average projection resulted from the 21 global climate models' (GCMs) simulation of historical climate and future climate change projection under three of the four RCPs: RCP2.6, RCP4.5, and RCP8.5. Projection datasets include the ensemble average and standard deviation of annual and monthly average temperature, maximum temperature, minimum temperature, and precipitation based on the 21 GCMs.

38. The projection for annual runoff adopts the rainfall-runoff coefficient method based on the precipitation from 21 GCMs' projection, and then the simple ensemble method is used for calculating the average of projected annual runoff. The average runoff and its ranges under different emission scenarios are also calculated based on this method.

### 4.2 Climate Projection in the Southern PRC and Guangdong Summary

39. **Southern PRC.** The projection results found that surface temperatures will continue to rise in the southern PRC, with greater increases in the northern region, and largest increases in the winter. Precipitation will increase, and spatio-temporal differences in precipitation will become larger with summer and autumn precipitation increasing, and spring and winter decreasing.[8]

40. **Guangdong.** The projection results indicate that the average temperature will increase. Winters will become warmer, with shortened cold periods and fewer days with low temperatures. However, the probability and intensity of cold disasters will increase. Average precipitation is projected to increase, as well as the intensity and frequency of extreme precipitation events. The probability of floods in summer and droughts in winter will increase (footnote 8).

**Table 3: Projected Changes in Temperature and Precipitation in the Southern PRC and Guangdong Compared with the Average from 1980 to 1999**

| | | **2031–2040** | **2051–2060** | **2091–2100** |
|---|---|---|---|---|
| **Southern PRC** | Temperature increase projected | 0.8°C–1.1°C | 1.3°C –1.8°C | 1.9°C –3.4°C |
| | Precipitation increase projected | 0%–1% | 1%–6% | 6%–7% |
| | | **2011–2040** | **2041–2070** | **2071–2100** |
| **Guangdong** | Temperature increase projected | 1.0°C | 1.9°C | 2.8°C |
| | Precipitation increase projected | 3% | 5% | 8% |

Source: Asian Development Bank.

41. **Sea-level rise.** In the next 30 years, the South China Sea is projected to have one of the fastest rises in sea level worldwide, rising 7.3–12.7 centimeters (cm) relative to 2010 baseline levels for the entire area, and 8.4–14.9 cm for Guangdong Province (footnote 8). Chaonan District has 17 km of coastline that is at risk. Sea-level rise will have adverse effects on the

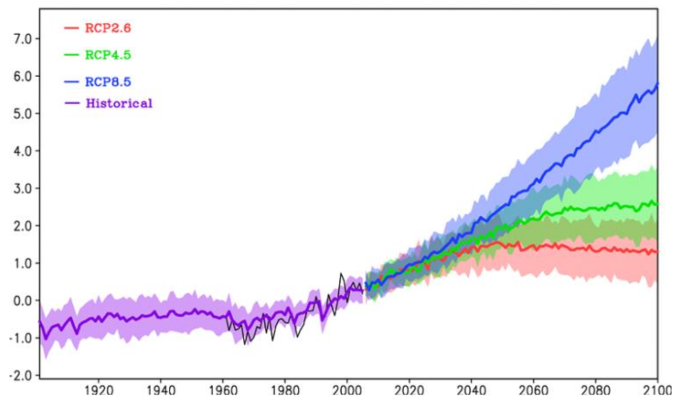
[8] Team for Climate Change Assessment Report of Southern People's Republic of China. 2013. *Climate Change Assessment Report of Southern People's Republic of China*. 2013. China Meteorological Press. Beijing.

environment and social economic development in coastal regions. Sea-level rise exacerbates storm surge and coastal erosions, diminishes the function of flooding-prevention engineering and port infrastructures, aggravates the difficulty of coastal urban flooding drainage and preventions, and deteriorates qualities of water resource and coastal ecosystem.

### 4.3 Projected Climate Change in Chaonan District

42. **Temperature.** Under all three RCP scenarios, the average temperature in Chaonan District rises. Before 2030, the three RCPs scenarios show a similar trend, but differ from each other after 2030. During 2011 to 2100, the temperature will rise by 0.07°C/10a, 0.19°C/10a, and 0.43°C/10a respectively under RCP2.6, RCP4.5, and RCP8.5 (Figure 11). The average temperature warming trend under RCP4.5 is close to the trend from 1951 to 2009 of the PRC (0.23°C/10a). However, the warming trend under the RCP8.5 scenario is nearly twice greater.

**Figure 11: Projected Annual Temperature Anomalies in Chaonan District under RCP2.6, RCP4. 5, and RCP8.5** (baseline: 1971–2000, unit: °C)




Source: Asian Development Bank.

43. All seasons increase in temperature in Chaonan District under RCP2.6, RCP4.5, and RCP8.5. The projected increase in temperature in autumn and winter are generally slightly higher than in spring and summer (Table 3).

**Box 3: Freezing Disaster in Guangdong in 2008**

From middle January to middle February 2008, a combination of severe low temperatures, rain, snow and freezing, caused serious disruption to traffic, electric power, and water supply, and caused damage in the agriculture, forestry, and fishery sectors. The direct economic loss was CNY16.64 billion, including 43.3 hectares of damaged crops, 2.1 thousand hectares of damaged pasture. As this coincided with the peak of Spring Festival transport, nearly one million passengers were stranded.

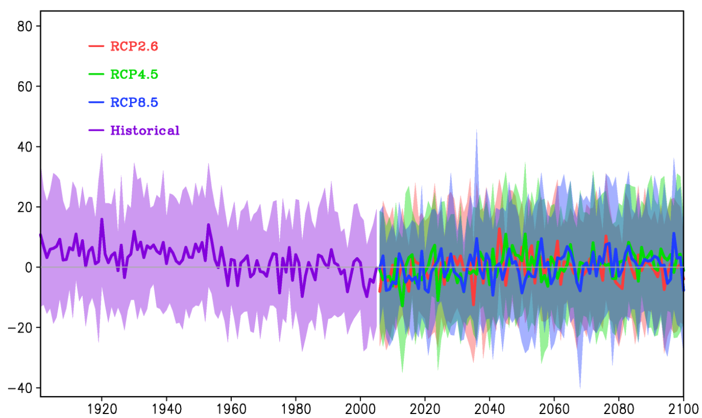
**Table 3: Projected Annual and Seasonal Temperature Changes for 2020s, 2050s, and 2080s under RCP2.6, RCP4.5, and RCP8.5** (baseline: 1971–2000, unit: °C)

| | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s |
| Annual | 0.90 | 1.28 | 1.24 | 0.95 | 1.66 | 2.04 | 1.00 | 2.27 | 3.62 |
| Spring | 0.88 | 1.29 | 1.25 | 0.97 | 1.65 | 2.05 | 0.95 | 2.23 | 3.57 |
| Summer | 0.87 | 1.16 | 1.18 | 0.90 | 1.56 | 1.92 | 0.98 | 2.18 | 3.53 |
| Autumn | 0.95 | 1.28 | 1.24 | 0.94 | 1.71 | 2.07 | 1.06 | 2.33 | 3.73 |
| Winter | 0.90 | 1.39 | 1.30 | 1.00 | 1.73 | 2.11 | 1.02 | 2.36 | 3.65 |

Source: Asian Development Bank.

44. **Precipitation.** Under all three RCP scenarios, the annual average precipitation in Chaonan District, precipitation is projected to vary slightly between -1.5% and 1.9% (Figure 12).

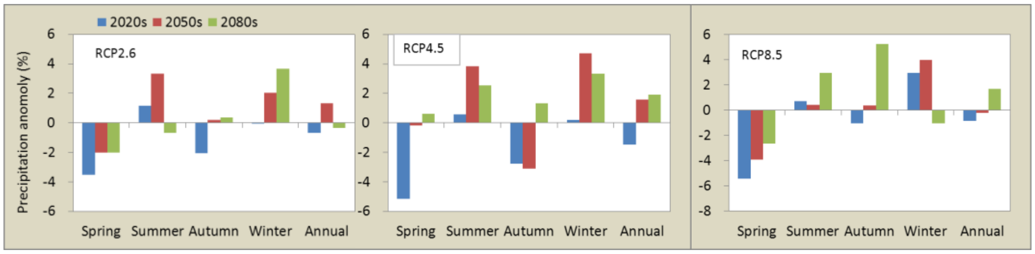
**Figure 12: Projected Annual Precipitation Anomalies in Chaonan District under RCP2.6, RCP4.5, and RCP8.5** (baseline: 1971–2000, unit: %)




Source: Asian Development Bank.

45. However, the projected changes in precipitation are characterized by large inter-annual and seasonal fluctuations. Annual total projected precipitation decreased under all three RCPs in the 2020s. Projected precipitation in spring decreased consistently in the 2020s, 2050s, and 2080s under all three RCPs scenarios (except for a slight increase in the 2050s under RCP 8.5), with a maximum decrease of 5.5%. Projected precipitation in summer and winter increased consistently (except for the summer of the 2020s in RCP8.5 and the winter of the 2080s under the RCP8.5) with a maximum increase in precipitation reaching 3.8% in the summer and 4.4% in the winter. Projected precipitation in autumn varied highly amongst the RCPs (Figure 13).

**Figure 13: Projected Seasonal Precipitation Anomalies in Chaonan District in RCPs**
(baseline: 1971–2000, unit: %)

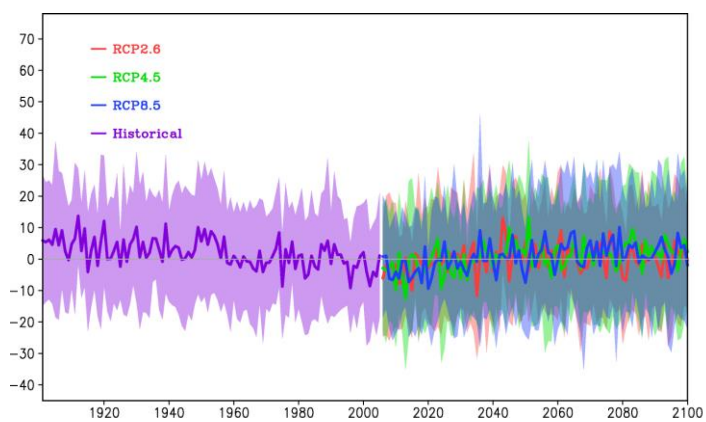



Source: Asian Development Bank.

### 4.4 Projection of Annual Runoff

46. The projected annual runoff is correlated with the projected annual precipitation. There is no significant trend for the projected ensemble mean annual runoff under RCP2.5, RCP4.6, and RCP8.5 (Figure 14). The projected annual runoff decreased 1.2%, 1.5%, and 1.4%, respectively under RCP2.5, RCP4.6, and RCP8.5 for the 2020s, with the range among GCMs highly variable, ranging from -21% to 18%. The projected annual runoff generally increased slightly for the 2050s and 2080s under all three RCP scenarios (Table 4).

**Figure 14: Projected Annual Runoff Anomalies in Chaonan District under RCP2.6, RCP4.5, and RCP8.5** (baseline: 1971–2000, unit: %)




Source: Asian Development Bank.

**Table 4: Projected Annual Runoff Changes (%) and Coefficient of Variation for the 2020s, 2050s, and 2080s under RCP2.6, RCP4.5, and RCP8.5** (baseline: 1971–2000)

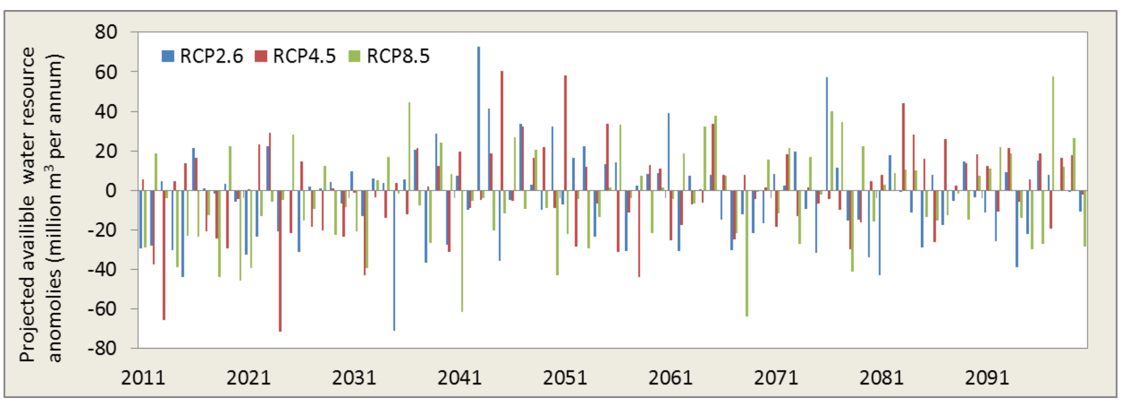
| Decades | Variable | RCP2.6 | | RCP4.5 | | RCP8.5 | |
|---|---|---|---|---|---|---|---|
| | | Average | Range | Average | Range | Average | Range |
| 2020s | Runoff | -1.2 | -20.8–18.3 | -1.5 | -20.8–17.8 | -1.4 | -20.4–17.6 |
| | CV | 0.7 | 0.1–0.9 | 0.6 | 0.1–0.8 | 0.7 | 0.2–0.9 |
| 2050s | Runoff | 1.5 | -17.0–20.0 | 1.8 | -18.4–22.0 | 1.4 | -20.4–23.1 |
| | CV | 0.6 | 0.1–0.8 | 0.6 | 0.2–0.8 | 0.6 | 0.1–0.8 |
| 2080s | Runoff | 0.4 | -19.0–19.9 | 2.3 | -19.5–24.1 | 2.4 | -19.7–24.5 |
| | CV | 0.8 | 0.1–1.1 | 1.3 | 0.1–1.6 | 0.7 | 0.1–0.9 |

Source: Asian Development Bank.

### 4.5 Projection of Water Resources

47. The surface water currently available in Chaonan District is about 548 million $m^3$. The projected water resources consistently decrease under the three RCPs up to 2040, with greater fluctuation subsequently (Figure 15). Water resources are generally projected to increase slightly for the 2050s and 2080s under all three RCPs (except for a decrease under RCP8.5 for the 2050s and RCP2.6 for the 2080s). The projected water resources for the three major water systems show the same changes.

**Figure 15: Projected Water Resources Anomalies in Chaonan District under RCP2.6, RCP4.5, and RCP8.5** (baseline: 1971–2000)




Source: Asian Development Bank.

**Table 5: Projected water resource anomalies for Chaonan District and the three major watersystems under RCP2.6, RCP4. 5 and RCP8.5 for 2020s, 2050s and 2080s**
(Unit: million $m^3$ annum)

| Decades | Chaonan District | | | Three Major Water Systems | | |
|---|---|---|---|---|---|---|
| | RCP2.6 | RCP4.5 | RCP8.5 | RCP2.6 | RCP4.5 | RCP8.5 |
| 2020s | -9.0 | -9.9 | -8.5 | -1.7 | -1.9 | -1.7 |
| 2050s | 2.7 | 3.7 | -5.2 | 0.5 | 0.7 | -1.0 |
| 2080s | -5.2 | 3.6 | 2.2 | -1.0 | 0.7 | 0.4 |

Source: Asian Development Bank.

## 5. Potential Climate Change Impact and Risk

48. Over the life of project (30 years), the climate projections indicate a general warming in Chaonan District, with the total estimated rise in temperature approximately 0.23°C to 1.4°C from the 2010 average of 21.6°C. In general, average winter and spring temperatures are expected to be warmer than currently. Total annual precipitation is expected to decline by 0.5% to 1.5%, with measurably drier springs and autumns, and slightly wetter summers and winters. Runoff is expected to decline by 1.2% to 1.5%. Given forecasted declines in precipitation and runoff, and increasing temperatures (and increased evapotranspiration as a result), surface water is projected to consistently decrease up to the early 2040s. Chaonan District is expected to have a decrease of between 8.5 million $m^3$/year to 9.9 million $m^3$/year, with the three major water systems (Jinxi, Qiufeng, and Longxi) declining by 1.7 million $m^3$/year to 1.9 million $m^3$/year. Sea-level rise is expected to be between 8.4 to 14.9 cm for Guandong Province, and Chaonan District has 17 km of coastline at risk. Saltwater intrusion may occur in freshwater bodies and aquifers. The frequency and intensity of extreme events such as droughts, floods, storm surges, and freezing is expected to increase based on the historical trend.

### 5.1 Methodology for Risk Assessment

49. To assess the risk to Chaonan project associated with climate change, a qualitative methodology based on expert judgment was used. The likelihood that an impact or consequence to the project activities would occur given climate change projections, the level of severity of the impact or consequence for the project activities (indicating that adaptation would be required), and the magnitude of the consequence or impact on project finances and results were used to determine the level of risk.

### 5.2 Methodology for Risk Assessment of Project Activities

50. **The likelihood** that an impact or consequence would occur given climate change projections was assessed as

| | | |
|---|---|---|
| Low | = 1 | given climate projections, little likelihood of impact or consequence |
| Medium | = 2 | given climate projections, some likelihood of impact or consequence |
| High | = 3 | given climate projections, high likelihood of impact or consequence |

51. **The level of severity** was characterized by

| | | |
|---|---|---|
| Low | = 1 | minor impacts to the project (little or no adaptation required) |
| Medium | = 2 | moderate impacts to the project (some adaptation required) |
| High | = 3 | major impacts (adaptation measures required to ensure achievement of planned results and ensure sustainability) |

52. **Magnitude of impact** on project finances and results was categorized as

| | | |
|---|---|---|
| Low | = 1 | no or very low cost or result impacts |
| Medium | = 2 | potential measurable financial or result impacts |
| High | = 3 | significant financial or result impacts |

53. **An assessment of the level of risk** was calculated by multiplying the probability of impact (or) consequence by the severity and magnitude of impact as follows:
Probability x (Severity x Magnitude)
For example: High probability x (High Severity x Low Magnitude) = 3 * (3*1) = 9

54. **Climate risk was defined as**

| | |
|---|---|
| Low risk | Score from 1 to 3 |
| Moderate risk | Score from 4 to 8 |
| High risk | Score from 9 to 27 |

**Table 6: Climate Change Risk Assessment for the Chaonan Project over Life of the Project (30 years)**

| Major Project Sectors | Climate-Related Drivers | Potential Primary Impacts | Probability | Severity | Magnitude | Risk Score | Risk Assess-ment |
|---|---|---|---|---|---|---|---|
| Water resources and processing | Increased average temperature | Increase in demand for water | High | Medium | Medium | 12 | High risk |
| | | Increased evapotranspiration | High | Medium | Low | 6 | Moderate risk |
| | Reduction in total precipitation | Lower reservoir yields | High | Medium | Low | 6 | Moderate risk |
| | | Insufficient water to meet demand | High | Medium | Low | 6 | Moderate risk |
| | | Decreased flow in water bodies | High | Low | Medium | 6 | Moderate risk |
| | Increased variability in precipitation seasonality | Water storage capacity insufficient | Low | Low | Low | 1 | Low risk |
| | | Insufficient water availability to operate at full capacity | Medium | Medium | Low | 4 | Moderate risk |
| | Increase in weather extremes | Reduced recharge of aquifers | High | Medium | Low | 6 | Moderate risk |
| | | Increased diffuse pollution, reduction in raw water quality | High | Medium | Low | 6 | Moderate risk |
| | | Increased flooding and risk of service loss | High | Medium | Medium | 12 | High risk |
| | Sea level rise | Saline intrusion | Low | Medium | Low | 2 | Low risk |
| Infrastructure and water pipe network | Increased average temperature | Impact on construction processes | Low | Low | Low | 1 | Low risk |
| | Increased variability in precipitation seasonality | Direct asset flooding (fluvial and pluvial) | Low | Medium | Medium | 4 | Moderate risk |
| | | Soil subsidence stresses pipe network | Low | Medium | Medium | 4 | Moderate risk |
| | Increase in weather extremes | Soil subsidence stresses pipe network | Medium | Medium | Low | 4 | Moderate risk |
| | | Storm and flood damage to assets | High | Medium | Medium | 12 | High risk |
| | | Frozen pipes burst | High | Medium | Low | 6 | Moderate risk |
| | Sea level rise | Direct asset flooding (tidal) and inundation | Low | Medium | Medium | 4 | Moderate risk |
| | | Saline intrusion degrades infrastructure | Low | Medium | Medium | 4 | Moderate risk |

Source: Asian Development Bank.

## 6. Challenges and Adaptation to Climate Change Risk

55. Some effects of climate change are unavoidable. Expected changes in the frequency and intensity of droughts and floods, and other extreme weather conditions will have impacts across the Chaonan project. The project will face an increased demand for water, due to both projected climate change, and socioeconomic trends. The project needs to adapt to these changing pressures and keep up to date with the latest technological advances to respond to these impacts.

### 6.1 Challenges

(i) The projected impacts of climate change in Guangdong Province and Chaonan District will compound an already difficult situation. Water resources are already stressed and the population is increasing. The project faces a number of challenges, includingMaintaining supplies of water to a growing population given projected decreases in total annual precipitation through the 2020s and rising temperatures;

(ii) Protecting vulnerable operational assets from flooding;

(iii) Nonrevenue water loss from burst or cracked pipes and maintenance costs to replace pipes; and

(iv) Planning for the great uncertainty associated with climate change.

### 6.2 Potential Adaptation Response Options

56. The proposed adaptive response to the effects of climate change on Chaonan project has four major elements: (i) reducing the future demand for water through increased efficiency, improved maintenance, and conservation of water; (ii) increasing the availability of raw water supply through the capture and storage of excess winter river flows; (iii) making water treatment more flexible and resilient; and (iv) reducing drought, flooding, sea level rise and subsidence risks to assets and infrastructure. The detailed potential adaptive response options are listed in Table 7.

**Table 7: Potential Adaptation Response Options to Reduce Risk for the Chaonan Project**

| Major Project Sectors | Climate-Related Drivers | Potential Primary Impacts | Risk Assessment | Options to Reduce Risk | Feasibility |
|---|---|---|---|---|---|
| Water resources and processing | Increased average temperature | Increase in demand for water | High risk | 1. Increase water conservation<br>2. Tariff reform | 1. Feasible—included in the planned capacity building and training<br>2. Feasible—incorporated in the project design |

| Major Project Sectors | Climate-Related Drivers | Potential Primary Impacts | Risk Assessment | Options to Reduce Risk | Feasibility |
|---|---|---|---|---|---|
| | | Increased evapo-transpiration | High risk | 1. Plant shade vegetation<br>2. Closed covers on storage tanks | 1. Feasible—the project included revegetation activities<br>2. Feasible—incorporated in the project design |
| | Reduction in total precipitation | Lower reservoir yields | High risk | 1. Improved watershed planning and management<br>2. Increase reservoir capacity | 1. Feasible—included in the project activities<br>2. Not feasible—difficult to increase |
| | | Insufficient water to meet demand | High risk | 1. Increase water conservation (grey water recycling, rainwater harvesting)<br>2. Increase efficiency of water use (drip irrigation)<br>3. Tariff reform<br>4. Improved maintenance of water pipe network<br>5. Connect piping network and shift water resources between three systems | 1. Feasible—through capacity building, included in the project design<br>2. Feasible—incorporated in the project design<br>3. Feasible—incorporated in the project design<br>4. Feasible—prioritization of pipe network replacement ongoing<br>5. Feasible—incorporated in the project design |
| | | Decreased flow in water bodies | Moderate risk | 1. Improved watershed planning and management | 1. Feasible—incorporated in the project design |
| | Increased variability in precipitation seasonality | Water storage capacity insufficient | Low risk | 1. Increase storage capacity<br>2. Increase reservoir capacity | 1. Feasible—could be achieved through improved reservoir operation; the project will make recommendations.<br>2. Not feasible—difficult to increase |
| | | Insufficient water availability to operate at full capacity | Moderate risk | 1. Increase storage capacity<br>2. Increase reservoir capacity<br>3. Flexible staff work schedules | 1. Feasible—could be achieved through improved reservoir operation; the project will make recommendations.<br>2. Not feasible—difficult to increase<br>3. Feasible—but outside of project scope |

| Major Project Sectors | Climate-Related Drivers | Potential Primary Impacts | Risk Assessment | Options to Reduce Risk | Feasibility |
|---|---|---|---|---|---|
| | Increase in weather extremes | Reduced recharge of aquifers | High risk | 1. Improved watershed planning and management<br>2. Monitoring of water extraction rates | 1. Feasible—incorporated in capacity building under the project<br>2. Feasible—incorporated in capacity building under the project |
| | | Increased diffuse pollution, reduction in raw water quality | High risk | 1. Improved watershed planning and management<br>2. Enforcement of pollution control regulations<br>3. Composting and biogas for agricultural waste<br>4. Improved fertilizer application | 1. Feasible—incorporated in capacity building under the project<br>2. Feasible—but responsibility of the Chaonan district and Shantou municipal governments<br>3. Feasible—but outside the project scope<br>4. Partially feasible—fertilizer use for reforestation will be restricted under the project; for agricultural use, the Chaonan district government needs to take measures. |
| | | Increased flooding and risk of service loss | High risk | 1. Drought and flood response plans<br>2. Design water network with cut-offs to avoid contamination | 1. Feasible—Chaonan district government is currently updating existing plans<br>2. Feasible—the project included a variety of reservoir protection activities |
| | Sea level rise | Saline intrusion | Low risk | 1. Monitoring of water quality<br>2. Design water network with cut-offs to avoid contamination | 1. Feasible—the project included water quality monitoring for reservoir intakes and pipe networks<br>2. Feasible—the project included a variety of reservoir protection activities |
| Infrastructure and water pipe network | Increased average temperature | Impact on construction processes | Low risk | 1. Use temperature resistant materials in construction | 1. Feasible—the project design considered this factor, but it is not a determining factor. |
| | Increased variability in precipitation seasonality | Direct asset flooding (fluvial and pluvial) | Moderate risk | 1. Drought and flood response plans<br>2. Design water network with cut-offs to avoid contamination<br>3. Raised foundation and waterproofing of electrical systems | 1. Feasible—currently updating existing plans<br>2. Feasible—the project included a variety of reservoir protection activities<br>3. Feasible—project design has taken this factor into consideration. |

| Major Project Sectors | Climate-Related Drivers | Potential Primary Impacts | Risk Assessment | Options to Reduce Risk | Feasibility |
|---|---|---|---|---|---|
| | | Soil subsidence stresses pipe network | Moderate risk | 1. Regular inspection and maintenance of pipe network<br>2. Install pipes that can withstand some flexing | 1. Feasible—incorporated in the project<br>2. Feasible—project design has taken this factor into consideration. |
| | Increase in weather extremes | Soil subsidence stresses pipe network | Moderate risk | 1. Regular inspection and maintenance of pipe network<br>2. Install pipes that can withstand some flexing | 1. Feasible—incorporated into the project design<br>2. Feasible—project design has taken this factor into consideration. |
| | | Storm and flood damage to assets | High risk | 1. Drought and flood response plans<br>2. Design water network with cut-offs to avoid contamination<br>3. Raised foundation and waterproofing of electrical systems<br>4. Coastal mangrove planting | 1. Feasible—Currently updating existing plans<br>2. Feasible—the project included a variety of reservoir protection activities<br>3. Feasible—project design has taken this factor into consideration.<br>4. Feasible—but outside the project scope |
| | | Frozen pipes burst | Moderate risk | 1. Regular inspection and maintenance of pipe network<br>2. Insulate pipes above ground and bury sufficiently deep in the ground | 1. Feasible—incorporated in the project design<br>2. Feasible—project design has taken this factor into consideration. |
| | Sea level rise | Direct asset flooding (tidal) and inundation | Moderate risk | 1. Drought and flood response plans<br>2. Design water network with cut-offs to avoid contamination<br>3. Raised foundation and waterproofing of electrical systems | 1. Feasible—currently updating existing plans<br>2. Feasible—the project included variety reservoir protection activities<br>3. Feasible—project design has taken this factor into consideration. |
| | | Saline intrusion degrades infrastructure | Moderate risk | 1. Design water network with cut-offs to avoid contamination<br>2. Raised foundation and waterproofing of electrical systems | 1. Feasible—the project included a variety of reservoir protection activities<br>2. Feasible—project design has taken this factor into consideration. |

| Major Project Sectors | Climate-Related Drivers | Potential Primary Impacts | Risk Assessment | Options to Reduce Risk | Feasibility |
|---|---|---|---|---|---|
| All project activities | All | All | Any | 1. Financial instruments—e.g., indemnity insurance, parametric insurance, contingent credit and catastrophe bonds<br>2. Linkage of planning, monitoring, and response<br>3. Awareness and capacity building | 1. Feasible—but outside the project scope, can recommend to local government to consider<br>2. Feasible—incorporated in the project design<br>3. Feasible—incorporated in the project design |

Source: Asian Development Bank.

### 6.3 Uncertainties

57. Key risks to the project activities are drought and flooding. It should be noted that uncertainties remain in the models used to make the climate projections. There will always be uncertainty about the size, rate of change and timing of climate change impacts. Analyses reported here focus on seasonal average trends and no data and/or analysis are provided here on projections of extreme rainfall events and/or dry spells. However, some general trends are emerging, such as increased temperatures and evapotranspiration, and increased climate variability.

58. It is suggested that the project should carefully consider those risks that are classified as moderate or high, and determine the level of risk that the project can bear. Actions to reduce risk that are no or low cost are recommended for adoption, and cost–benefit analysis should help determine the level of effort for more costly interventions.

59. Depending upon the project budget, the risk assessment, and other factors, it may be most effective to set in place engineering solutions, but not fully implement; and make costly infrastructure changes during later phases. Monitoring of climate risks and opportunities, and future re-assessments of risks is highly recommended.