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Tetra Tech International Development B.V.
Jan Luijkenstraat 92 C, 1071 CT
Amsterdam, The Netherlands

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Prepared By	Dr. Renalda El-Samra Climate Change Specialist & ESIA Team	Dr. Renalda El-Samra Climate Change Specialist & ESIA Team		
Checked By	Timothy Young SPM Manuel BÉNARD DTL	Timothy Young SPM Manuel BÉNARD DTL		
Approved By	Mathieu ARNDT TL	Mathieu ARNDT TL		

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Glossary of Terms and Abbreviations

AAWDCP	Aqaba Amman Water Desalination and Conveyance Project
ADC	Aqaba Development Corporation
ASEZA	Aqaba Special Economic Zone Authority
BAU	Business as Usual
CAPEX	Capital Expenditure
CDI	Combined Drought Index
CTD	Conductivity (salinity) – Temperature – Depth
CUSUM	Cumulative Sum
CVRA	Climate Vulnerability and Risk Assessment
DO	Dissolved Oxygen
DRR	Disaster Reduction Unit
E	Exposure
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
ESCWA	United Nations Economic and Social commission for Western Asia
GCMs	Global Circulation Models
GHGs	Greenhouse Gases
GIS	Geographic Information Systems
I&C	Instrumentation and Control
IHE	Institute for Hydraulic and Environmental Engineering
IPCC	Intergovernmental Panel on Climate Change
IPS	Intake Pump Station
JMD	Jordan Metrology Department
JRV	Jordan Rift Valley
Km	Kilometers
MCM/year	Million Cubic Meters per Year
MENA	Middle East North Africa
MWI	Ministry of Water and Irrigation
NCEP	National Centers for Environmental Prediction
OPEX	Operational Expenditures
PS	Pump Station
ppt	Part per Trillion

RCPs	Representative Concentration Pathways
RICCAR	Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources in the Arab Region
RO	Reverse Osmosis
S	Sensitivity
SDSM	Statistical Downscaling Model
SLR	Sea Level Rise
SNC	Second National Report
SWAT	Soil and Water Assessment Tool
SWRO	Sea Water Reverse Osmosis
THMs	Trihalomethanes
TNC	Third National Report
Tor	Terms of Reference
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
V	Vulnerability
WAJ	Water Authority of Jordan
WEAP	Water Evaluation and Planning System
WFP	World Food Programme
WWTP	Wastewater Treatment Plant

1. Introduction

The climate is warming due to increased radiative forcing produced by anthropogenic emissions of greenhouse gases (GHGs). Regardless of the future emission scenario adopted, this warming is likely to exacerbate water scarcity in many regions of the world and lead to various other adverse impacts on human socio-economic activities and well-being.

In recent years, various regions have witnessed seasonal weather changes that were associated with negative environmental impacts and that led to socio-economic burdens across many countries. In addition, recent research indicates potentially greater changes in regional weather under future climate conditions (IPCC, 2013). In particular, climate change has been reported to intervene with the frequency and intensity of extreme events (Christidis et al., 2005). Examples of such events are heatwaves, droughts, and floods that have adverse effects on important aspects of our society and economy, such as water resources, crop yield, and human health (Seneviratne et al., 2014). Therefore, understanding vulnerability to climate change and corresponding mitigation measures and adaptation strategies to potential negative impacts, became imperative at both regional and local levels.

Covering a total area of about 90,000 km², Jordan lies in the heart of the Middle East. It borders Iraq, Israel, Palestine, Saudi Arabia and Syria. The country has a combination of semi-arid and Mediterranean climates. Annual precipitation varies from less than 50 mm in the eastern and southern desert regions to 600 mm (Figure *1*) in the northern highlands (Shehadeh and Ananbeh, 2013), some of which fall as snow (UNDP, 2010).

In general, Jordan has warm, dry summers and mild wet winters, with annual average temperatures ranging from 12°C to 25°C and summertime highs reaching 35°C in the desert. Precipitation falls exclusively in the winter season. Occasionally, heavy rainstorms cause flash floods of short duration in surface watercourses (wadis). Part of the precipitation recharges the groundwater systems. Groundwater from springs may emerge at a flow rate of less than 1 litre per second (L/s) to more than 50 L/s. In certain places, springs and other forms of groundwater discharge feed rivers that carry water all year around[1].

[1] https://water.fanack.com/jordan/geography-climate-population/

2. Climate and Climate Trends

Jordan is situated in the eastern Mediterranean region. Jordan has three ecological zones (GEF/UNDP, 2014):

- The Jordan Valley, which sits 200–400 meters below sea level, experiences warm winters (19°C–22°C) and hot summers (38°C–39°C), with average annual rainfall ranging between 100–300 mm.
- The Western Highlands experience the highest precipitation levels: rainfall averages 350–500 mm per year and temperatures range from 9°C–13°C in the winter to 26°C–29°C in the summer.
- The Badia, an arid and semi-arid area to the east, covers approximately 85 percent of the country. Average annual rainfall levels fall below 200 mm, and temperatures range from 14°C–16°C in the winter to 35°C–37°C in the summer.

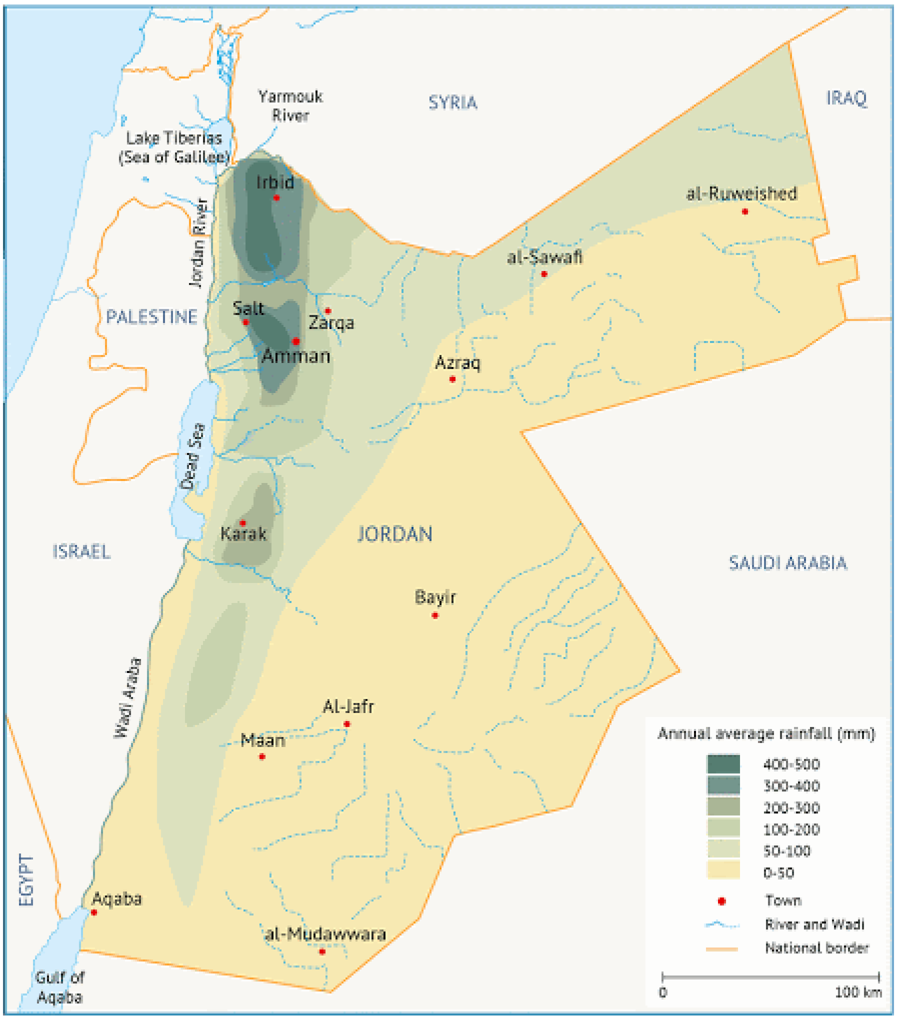


Figure 1: Annual Average Rainfall and Precipitation. (Source: water.*fanack.com*)

The climate is influenced by Jordan's location between the subtropical aridity of the Arabian desert areas and the subtropical humidity of the eastern Mediterranean area. January is the coldest month, with temperatures from 5°C to 10°C, and August is the hottest month at 20°C to 35°C. Daily temperatures can be very hot, especially in the summer; on some days it can be 40°C or more, especially when the Scirocco, a hot, dry southerly wind blows. These winds can sometimes be very strong and can cause sandstorms.

Rainfall varies from season to season and from year to year. Precipitation is often concentrated in violent storms, causing erosion and local flooding, especially in the winter months.

Koeppen-Geiger classification: The Climate of Jordan can be classified as BSh climate, a hot Climate with dry summers and the annual average Temperature above 18°C. The eastern and southern areas of Jordan have a BWh Climate; a hot, dry desert climate with annual average temperatures above 18°C[2].

2.1. Historic Trends in Climate in Jordan

Based on long historical data published by the Jordan Metrology Department (JMD), climatic variables are changing significantly at both national and station levels, indicating that climate change is becoming more apparent (GEF/UNDP, 2014). Both the Mann-Kendall rank trend test and linear regression trends indicate that the annual precipitation tends to decrease significantly with time at a rate of 1.2 mm per year. Simultaneously, the mean, maximum and minimum air temperature tends to increase significantly by 0.02, 0.01, and 0.03 °C/year, respectively. On the other hand, the relative humidity tends to increase significantly by an average of 0.08 %/year, while class A-pan evaporation seems to have non-realistic estimations of decreasing significantly by 0.088 mm/year. The number of days of dust storm tends to decrease significantly by 0.09 days/year and 0.06 days/year for visibility less than 1 km and 5 km. In addition, the historic data tested on both annual and monthly basis indicated that precipitation reduction is highly significant during the whole rainy season except for January. Similarly, during the dry seasons of June, July and August, the precipitation tended to increase over time, although this increase is considered negligible in its quantity as indicated by the magnitude of the slope (GEF/UNDP, 2014).

2.1.1. Temperature

The mean annual temperature in Jordan for the period 1901-2016 is 18.65°C (Figure *2*) while Figure *3* shows mean historical monthly temperature for the country during the time period 1901-2016. The dataset was produced by the Climatic Research Unit of University of East Anglia.

The following trends in temperature have been observed:

- The annual maximum temperature has increased by 0.3-1.8°C since the 1960s.
- The annual minimum temperature has increased by 0.4-2.8°C since the 1960s.
- The mean annual temperature has increased by 0.89°C since 1900.

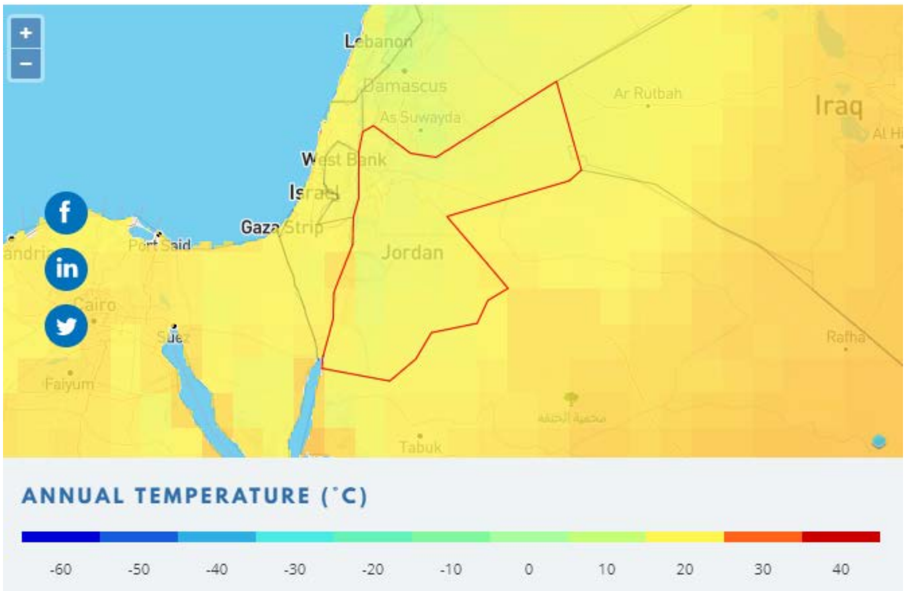


Figure 2: Annual Temperature of Jordan for 1901-2016 (https://climateknowledgeportal.worldbank.org/)

[2] https://www.weatheronline.co.uk/reports/climate/Jordan.htm

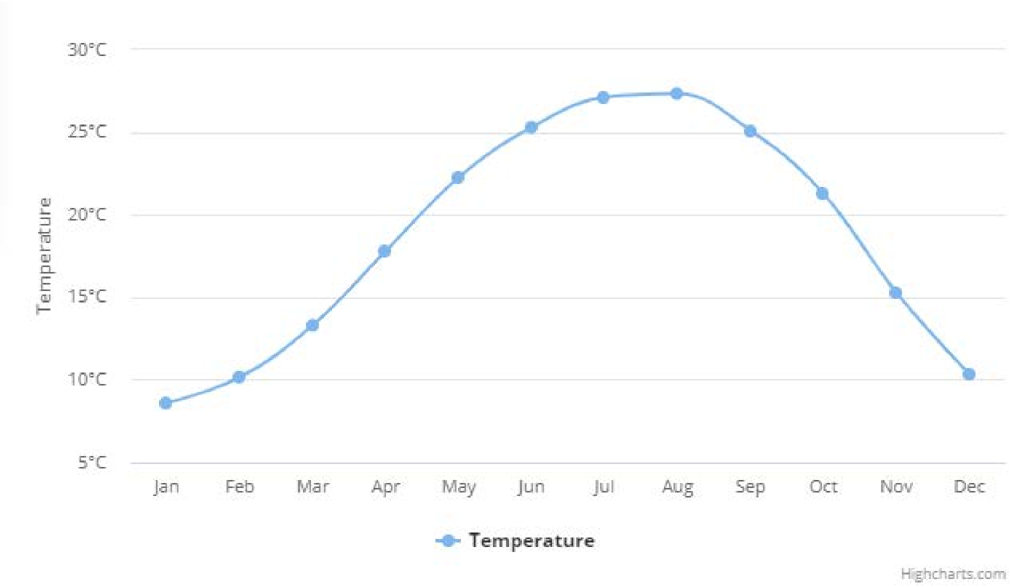


Figure 3: Average Monthly Temperature of Jordan for 1901-2016 (https://climateknowledgeportal.worldbank.org/)

Table *1* below provides the mean historical monthly temperature for Jordan during the time period 1901-2016.

Table 1: Average Monthly Temperatures of Jordan 1901-2016

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°C	9.20	10.76	14.17	18.68	23.10	26.27	28.17	28.40	25.99	22.09	15.59	10.80

Source: https://climateknowledgeportal.worldbank.org/

Trends since the 1960s include (USAID, 2017):

- Rise in annual maximum temperature of 0.3-1.8°C and rise in annual minimum temperature of 0.4–2.8°C across all regions (minimum temperatures rose at a faster pace than maximum temperatures).
- Increase in the average number of heat waves across the country, particularly in the desert.
- Increase in the number of consecutive dry days nationwide (highest in the desert, followed by the highlands and then the Jordan Valley).

A study conducted by Smadi (2006) examined changes in annual and seasonal mean (minimum and maximum) temperatures variations in Jordan during the 20th century covering the period 1923 to 2003. The analyses focused on the time series records at the Amman Airport Meteorological station. The occurrence of abrupt changes and trends were examined using cumulative sum charts and bootstrapping and the Mann-Kendall rank test. Statistically significant abrupt changes and trends have been detected. Major change points in the mean minimum (night-time) and mean maximum (daytime) temperatures occurred in 1957 and 1967, respectively. A minor change point in the annual mean maximum temperature also occurred in 1954, which is essential agreement with the detected change in minimum temperature. The analysis showed a significant warming trend after the years 1957 and 1967 for the minimum and maximum temperatures, respectively. The analysis of maximum temperatures showed a significant warming trend after the year 1967 for the summer season with a rate of temperature increase of 0.038°C/year. The analysis of minimum temperatures showed a significant warming trend after the year 1957 for all seasons.

On the other hand, Hamdi et al. (2009) used data from six meteorological stations distributed around Jordan and analyzed it using several parametric and nonparametric statistical approaches including Mann-Kendall, Linear Regression, Cumulative Sum (CUSUM), Rank Sum, Student's t-test, Rank Difference, Auto Correlation and Skewness-Kurtosis Normality test. Their findings revealed that minimum air temperature has increased since the seventies of the last century. This increase indicates a slight change in regional climate. Annual maximum air temperature records did not show clear trends, but annual minimum temperatures have increased while the annual range of temperature have decreased. Decreasing temperature range proves that the earth is becoming more efficient in trapping terrestrial infrared radiation, which is responsible of the global warming.

Another study conducted by Matouq et al. (2013) examined meteorological data such as rainfall and temperatures, covering the period between 1979 and 2008. The data were simulated using the geographic information systems (GIS) and computer software “MATLAB”. The output results were converted into geographical maps. Three parameters were analyzed: annual mean maximum temperature, annual mean minimum temperature, and mean annual rainfall during the period (1979–2008). Although local temperatures fluctuate naturally, but over the past 50 years, the mean local temperature in Jordan has increased rapidly since 1992 by 1.5–2°C.

Sada et al. (2015) investigated the impact of climate change on air temperature in the Jordanian Badia, which has fragile environmental ecosystems. Meteorological data for six meteorological stations in the Badia (Mafraq, Safawi, Rwaished, Azraq, Um El-Jumal, and Ramtha) in addition to Dara’a in south Syria, and Turaif and Guriat in north Saudi-Arabia obtained from the Jordanian Ministry of Water and Irrigation (MWI) and the USA National Oceanic and Atmospheric Administration are used to identify the changes in air temperature. The Statistical Package for the Social Sciences (SPSS) was utilized to retrieve a regression trend between atmospheric carbon dioxide and ambient air temperature and to project future air temperatures at the nine stations considered in this study. Findings indicated that air temperature is increasing at an annual rate of 0.02-0.06 °C/year.

2.1.2. Precipitation

The mean annual precipitation in Jordan is 113.52 mm for the period 1901 to 2016 (Figure *4*). The following trends in precipitation have been observed:

- Global Historical Climatology Network data for the country indicates a 2.92 mm/month per century reduction in average annual precipitation since 1900.
- Most local station records indicate that precipitation dropped from 94 mm to 80 mm during the last 10 years for the period 1937/38 to 2004/2005.
- Annual precipitation rates show decreases at most meteorological stations.

Figure *5* below shows mean historical monthly rainfall for Jordan during the time period 1901-2016. The dataset was produced by the Climatic Research Unit of University of East Anglia.

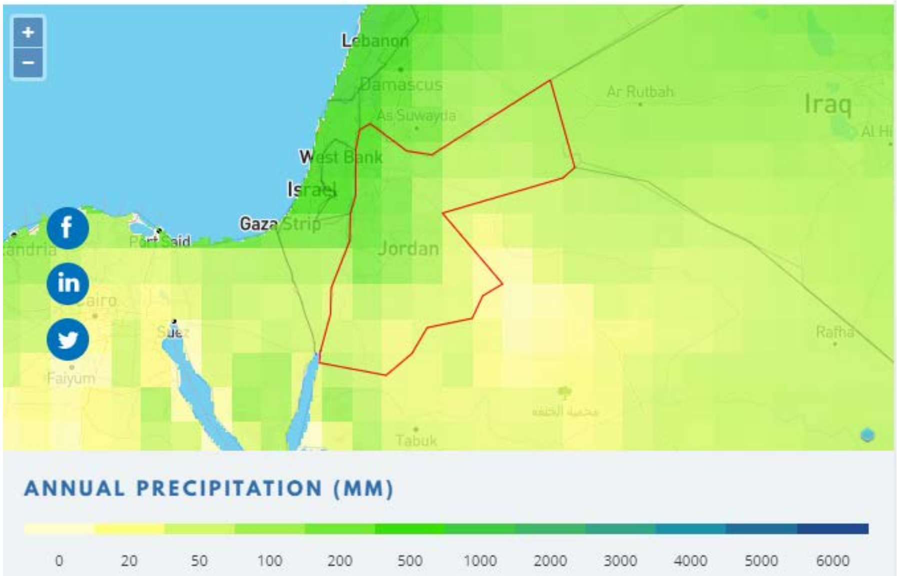


Figure 4: Annual Rainfall of Jordan for 1901-2016 (https://climateknowledgeportal.worldbank.org/)

Table *2* provides the mean historical monthly rainfall for Jordan during the time period 1901-2016.

Table 2: Average Monthly Rainfall of Jordan 1901-2016 (https://climateknowledgeportal.worldbank.org/)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	24.49	22.88	17.55	9.28	3.62	0.24	0.58	0.30	0.11	3.70	11.20	19.45

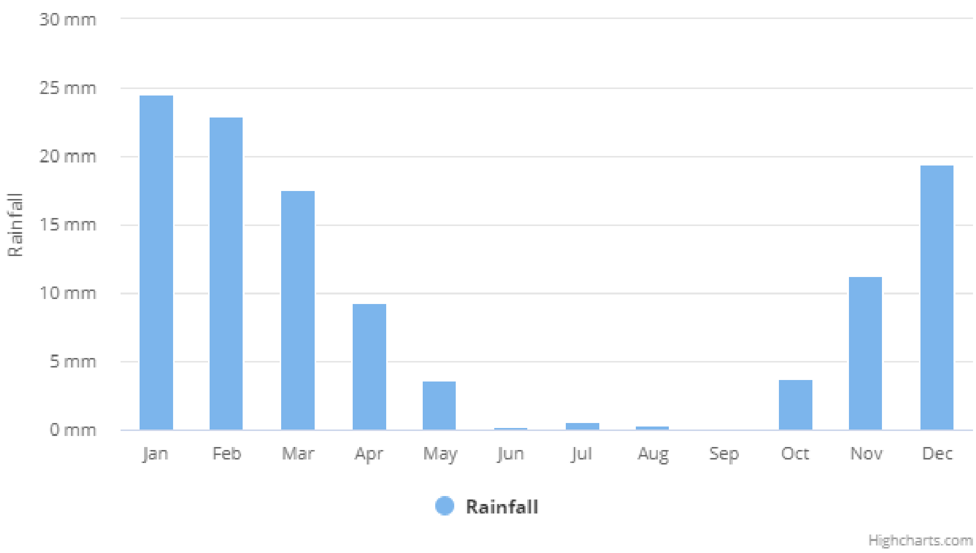


Figure 5: Average Monthly Rainfall of Jordan for 1901-2016 (https://climateknowledgeportal.worldbank.org/)

Estimates of long-term records (1937/1938-2000/2001) of rainfall distribution over Jordan indicate that the average annual rainfall volume over the country is around 8,360 MCM. Aridity and water scarcity make Jordan environmentally sensitive to climate change. More than 80% of the country is unpopulated due to desert conditions, where annual precipitation is under 50 mm. Water availability is mainly dependent on rainfall which can vary greatly from year to year (Ministry of Foreign Affairs of the Netherlands, 2018).

While there is some difference in the analysis of trends, there is convergence that the frequency of drought is increasing and that this trend will continue. The results of an analysis by the International Center for Agricultural Research for the period 1901-2010 indicates that annual precipitation has been declining for a long time and that this trend is significant in all of Jordan (Ministry of Foreign Affairs of the Netherlands, 2018). Historical climate trends since the 1960s include a decline in annual precipitation by 5–20 percent across the country, except Ras Muneef in the highlands and Ruwaished in the Badia, where rainfall has increased by 5–10 percent.

Hammouri and El-Naqa (2007) conducted a research to assess drought conditions in Amman-Zarqa basin and reported that the drought periods had occurred on a regular basis during the last 50 years in the investigated catchment area. To the contrary, Dahamsheh and Aksoy (2007) did not find any trends in Jordanian precipitation data at 13 stations investigated for the years 1953–2002. Al-Qudah and Smadi (2011) reported that Jordan, which is part of a semi-arid zone, is vulnerable to climate change. Ghanem (2011) analyzed meteorological data of the rainy seasons from 1956/1957 to 2005/2006 at 11 stations distributed within Amman area and reported that annual precipitation is decreasing by about 0.4 mm/year, but with no statistical significance. He also reported that the running means showed two wet periods (1962/1963–1973/1974 and 1987/1988–1993/1994) and two dry periods that occurred in the beginning and the end of the study period. Matouq et al. (2013) showed that no change has occurred in the mean annual rainfall in both northern and eastern part, while it has increased in the central region of Jordan during the period 1979–2008. Sada et al. (2015) found that annual precipitation is decreasing at an annual rate 2.6-0.5 mm/year.

Al Adaili et al. (2019) generated a drought vulnerability map (Figure *6*) with an emphasis on the severity and probability of drought occurrence, and proposed adaption measures based on groundwater sector impact chain analysis by incorporating numerical scorings for exposure, sensitivity, and adaptive capacities at groundwater basin and Jordanian district levels.

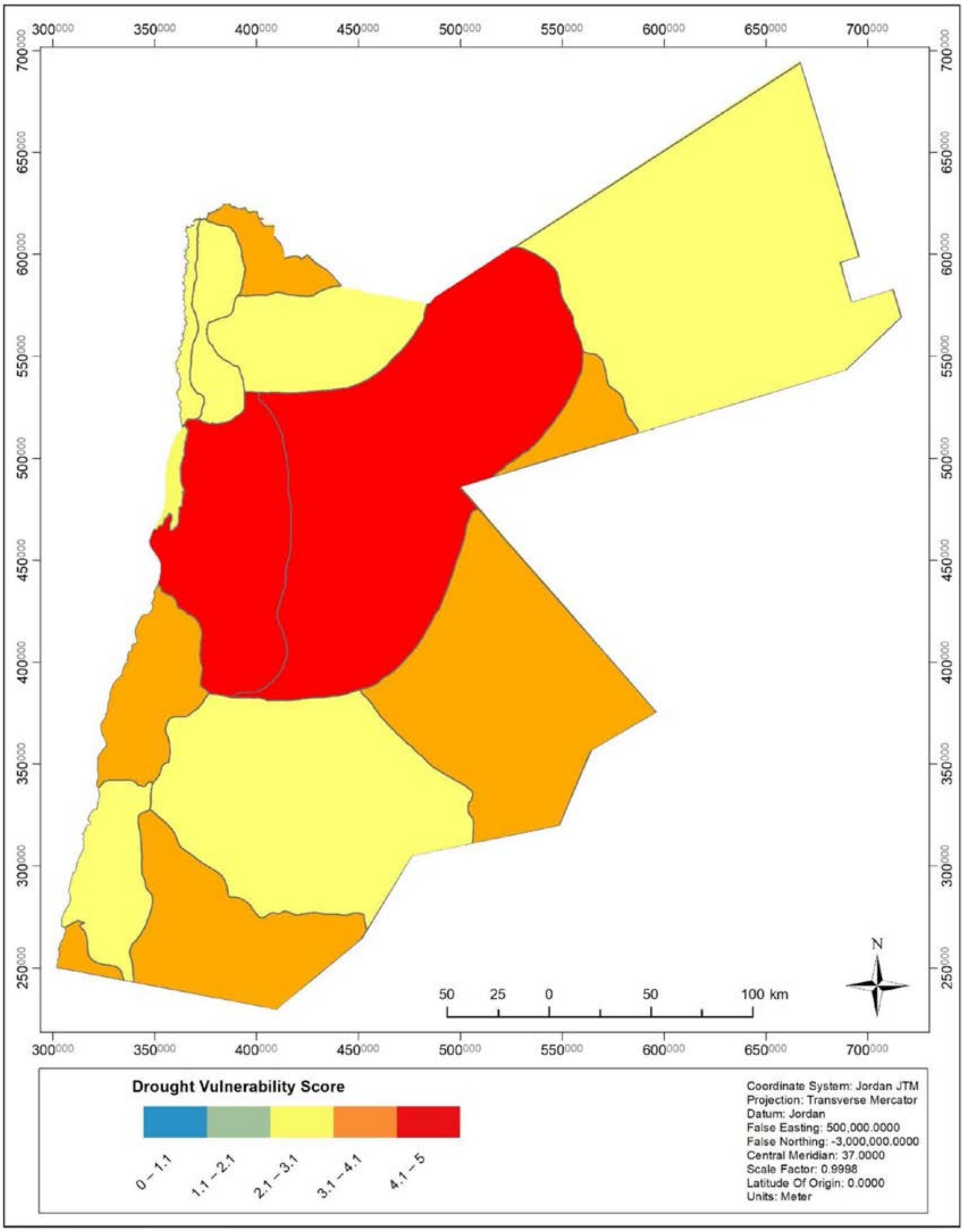


Figure 6: Drought Vulnerability Score Map for Jordan (Al Adaileh et al., 2019)

Drought impacts on groundwater basins were investigated based on measurements of severity and probability of drought occurrence, and drought exposure over the whole country computed by means of a combined drought index (CDI) that included the precipitation drought index, temperature drought index, and vegetation drought index from 1980 to 2017 . Results indicated that drought in Jordan is characterized by a temporal and spatial variability regarding probability and severity. The most prolonged drought events ranged from mild to moderate, with long periods of exposure that may extend for up to 13 consecutive years.

On another note, floods do not occur regularly in Jordan. However, the kingdom witnessed recently a sharp increase in flood severity and frequency of occurrence as observed by relevant government officials. Floods are formed on a seasonal basis in some areas of the kingdom either at the beginning or end of the rainy season, during periods of unstable weather conditions. Floods and flash floods remain the main cause of death due to natural disasters in the country; representing around 53% of disaster-related mortality between 1980 and 2012 (UNISDR, 2013) and producing losses in properties, and destruction of infrastructure.

Like in any other arid to semi-arid countries, flash floods pose an important threat to many of the settlements in the country that are located in the low land areas of the mountainous ranges (such as the archaeological city of Petra), or cities located downstream of a catchment area in a flat topography (Ma'an city) or in alluvial fans such as the case of Aqaba city. Despite the large threat posed on some parts of the country by the floods, there is limited documented literature on floods in Jordan. Hence, most of the information cited in this section is based on electronic news, internet publications and few references provided by the disaster reduction unit (DRR) in Aqaba Special Economic Zone Authority (SWIM, 2014).

One of the wadis ranked with the highest potential for risk and damage in Jordan is Wadi Yutum (including its tributary Wadi Umran, covering a watershed area on nearly 4,000 km^2), a tributary to the Red Sea at the Gulf of Aqaba notorious for producing extreme flood events that have damaged structures located in the active flood channel. In February 2006, both Aqaba and Ma'an in South Jordan witnessed a large flood in lower Wadi Yutum and in Wadi Ouhadah; west of Ma'an city killing eight people. The peak flow reached some 550 m^3/second in Wadi Yutum (estimated to be between a 10- and 40-year event), and around 320 m^3/second in Wadi Ouhadah (USAID, 2011). The incidence, which was of regional nature (involving Palestine, Saudi Arabia and Israel) resulted in the destruction of part of the Disi-Aqaba water transmission pipeline; the main water line to Aqaba city, and the disruption of water supply for two weeks and of power supply, and caused scour and erosion that impacted concrete revetments and gabion structures within the Wadi channel. The floods also disrupted Aqaba Wastewater Treatment Plant (WWTP) for several months and Aqaba airport due to water flow and sediments transported to the runway (SWIM, 2014).To attenuate the risk of flash flooding caused by this wadi, Aqaba Development Corporation (ADC) constructed multiple successive dams and upgraded the conveyance and protection measures (Figure 7).

Figure 7: Constructed Dams in Wadi Yutum (Source: Google Earth, 2021)

In 2013, an extreme flood event hit the whole country; in the northern parts (Mafraq, Zarqa, Amman and Yarmouk River), the Jordan Rift Valley (JRV) in the West (including the Dead Sea, and Jordan River) and the southern part in Ma'an and Aqaba. The floods submerged the streets in the main cities of Amman and Zarqa with rainwater that inundated the vehicles. In the Jordan Rift Valley, about 8,500 acres of agricultural land adjacent to the Jordan River were submerged with water. Floods also destroyed all the plantations affected by heavy runoff and soil erosion - from Adasiyeh in the North of JRV, to Damia in the middle. Fish farms in Manshiyeh and Abu Obaida were also destroyed. In the southern part of the country, the road linking Aqaba to the Dead Sea was closed by eroded sediments, while Aqaba airport was closed for two days (SWIM, 2014).

The Jordanian coast of the Gulf of Aqaba is characterized by rocky coral reef structures interspaced by valleys running down from the surrounding mountains. These valleys are dry most of the year but experience a couple of flash floods per year. ASEZA has established a system of dams to harvest rainwater and to reduce flood impact on the coastal developments and habitats. The terrestrial area of the project belongs to a flooding zone and the exposure of the project characterized as medium (baseline and future) according to UNWFP (2019) study (Figure *8*).

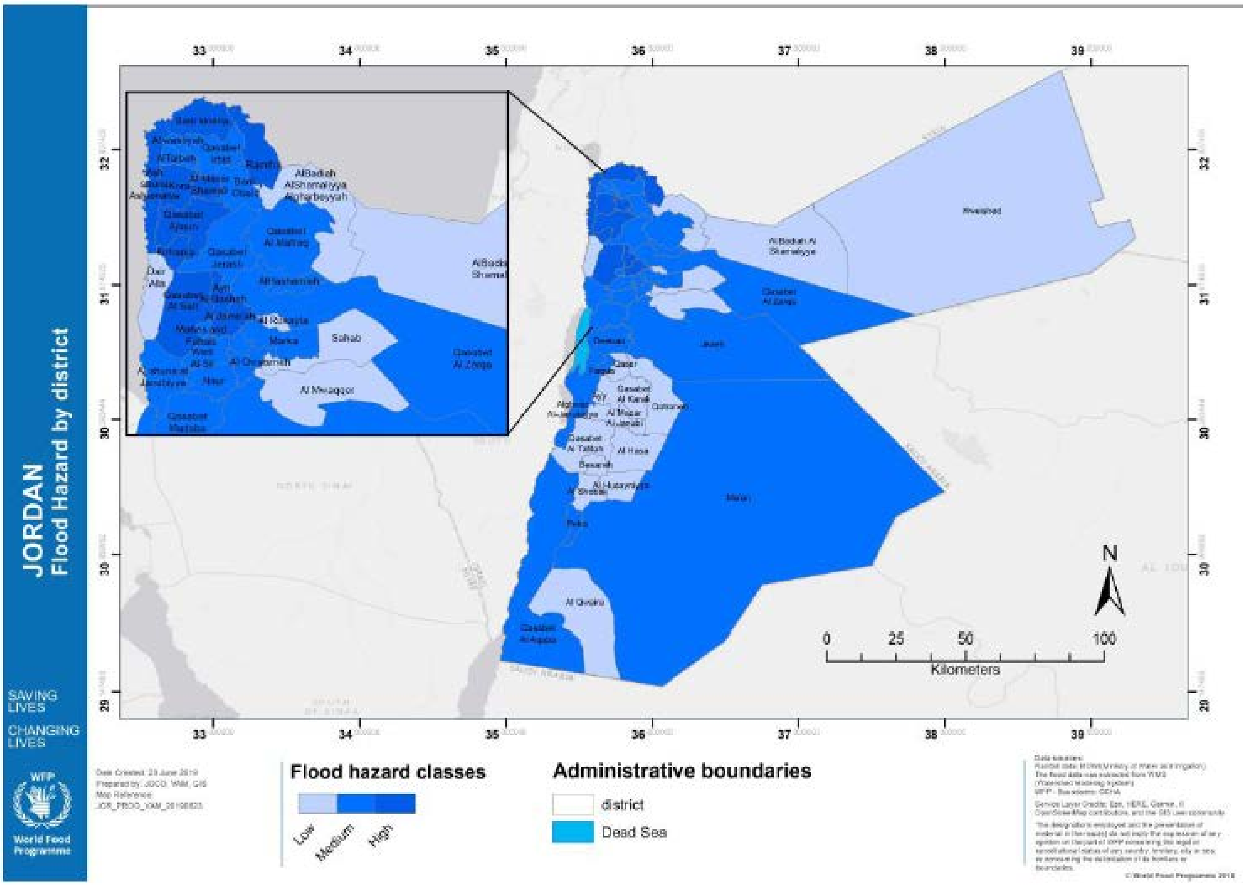


Figure 8: Flood Hazard Prone Area Map (UNWFP, 2019)

Drews (2015) modeled the response in surge height to wind direction is a sinusoidal curve for port cities at the end of a long inlet, as well as for cities exposed along a straight coastline. Surge height depends on the cosine of the angle between the wind direction and the major axis of the narrow gulf. The Red Sea is a long narrow body of water between northeast Africa and the Arabian Peninsula. The northern end splits around the Sinai Peninsula into the shallow Gulf of Suez to the west, and the much deeper Gulf of Aqaba to the east. Figure 9 shows the water level in the northern Red Sea when winds are blowing out of the southeast (from 300° Cartesian). This wind direction generates the maximum surge at Suez, since the incoming wind is aligned with the Gulf of Suez and the Red Sea proper along the longest possible fetch distance. The minimum surge height was the lowest at Aqaba with a level of 0.55 m.

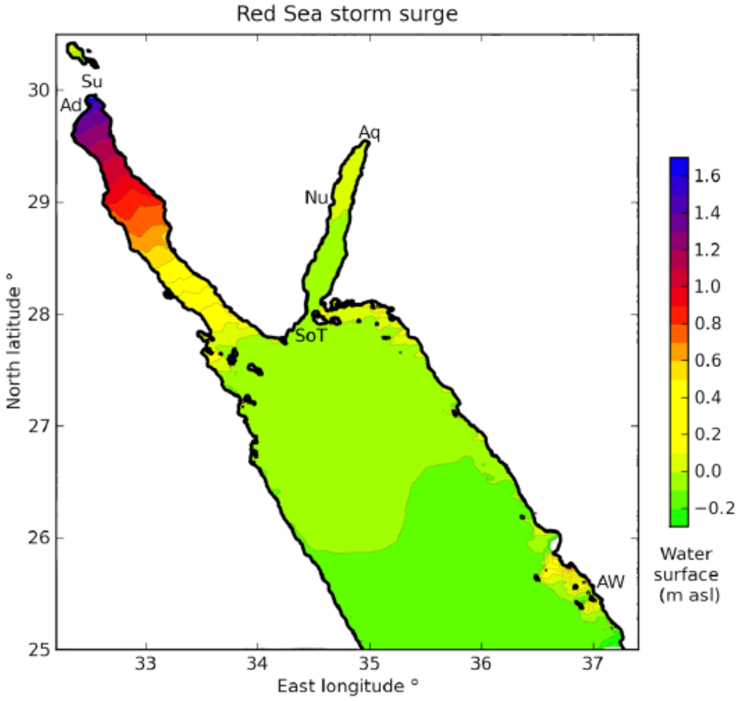


Figure 9: Red Sea Surge Height with Wind Blowing from Southeast (Drews, 2015)

2.1.3. Sea Level Rise

The Gulf of Aqaba is located on the Red Sea which is one of the extensions of the Indian Ocean in the northwestern part that connects to it through the Arabian Sea. The Red Sea water is very saline and dense due to a high evaporation rate, lack of precipitations, and freshwater input (Alawad et al., 2019).

Values for the 20th century global sea level rise (SLR) based on tide gauges records published during the 1990s, are in the range 1 to 2 mm/year (Church and White, 2011). The largest contribution of SLR arises from thermal expansion due to warming of the oceans that have mainly occurred since the 1950s. Although changes in global mean sea-level could reflect changes in sea-level at the Gulf of Aqaba, the relationship between global mean SLR and local SLR will depend on a combination of factors, including changes in ocean circulation (which can alter sea-levels at local and regional scales), variations in oceanic levels due to thermal expansion and relative sea-level change associated with land movements (i.e. geological uplift and/or subsidence) (Nicholls and Klein, 2005; Harvey and Nicholls, 2006). The Gulf of Aqaba is an extension of the Levantine or Dead Sea Fault, and part of the Red Sea Rift that are tectonically active leaving the possibility of sea level increase.

Monismith and Genin (2004) discussed observations of tidal variations in currents and elevation taken in the Gulf of Aqaba (Eilat) over the fringing coral reef at Eilat, Israel. Tidal currents and water levels in the Northern Gulf of Aqaba show strongly the effects of remote forcing. Water levels reflect remote forcing, with annual variations in sea surface height in the Gulf driven by wind-induced setup in the main part of the Red Sea, although winds on the Gulf itself are also important. It appears that observed tidal currents are the result of internal tides generated at the Strait of Tiran. This might be attributed to the annual variation in currents to variations in generation and propagation associated with changes in stratification strength and structure throughout the year. When the Gulf is strongly stratified in summer, tidal currents are strong, and when stratification is weak tidal currents are weak.

2.2. Future Climate Scenarios for Jordan

According to Jordan's Third National Communication to the UNFCCC (GEF/UNDP, 2014), projected climatic changes in the Arab region and their impacts on natural resources were recently assessed through the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources in the Arab Region (RICCAR) which was led by the United Nations Economic and Social commission for Western Asia

(ESCWA). RICCAR used an integrated assessment methodology that combined climate change impact assessment with socio-economic and environmental vulnerability assessment, based on the generation of dynamically downscaled regional climate modeling projection covering the Arab/Middle East North Africa (MENA) domain and a series of associated ensemble outputs.

Regional climate modelling outputs were generated by SMHI using the Rossby Centre Regional Atmospheric Model (RCA4), forced at its boundaries by three state-of- the-art Global Circulation Models (GCMs), namely EC-Earth, CNRM-CM5 and GFDL- ESM2M. An average of the three-model output ("ensemble") was derived for Representative Concentration Pathways (RCP) 4.5 (moderate case scenario) and RCP 8.5 (current scenario with the highest levels of potential GHG emissions or worst-case scenario) for the various climate variables up to the end of the 21st century at a horizontal resolution of 50km x 50km (RICCAR, 2017).

The projections were then linked to two regional hydrological models to specifically analyze the impact of climate change on the region's freshwater resources (Figure *10*). These outputs were in turn used as inputs into a regional vulnerability assessment to identify hotspots across the Arab region. RICCAR results show a consistent warming trend with a general increase in the frequency of warm days and longer summer periods in the Arab region. The rise in temperature becomes increasingly evident across the region by the end of the century (RICCAR, 2017).

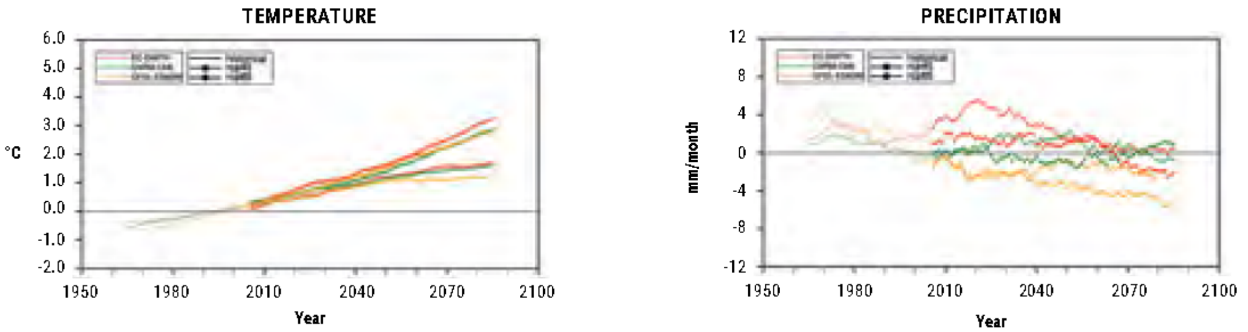


Figure 10: Mean Change in Temperature and Precipitation Over Time for Ensemble of RCP 4.5 and RCP 8.5 Projections for the Jordan River Basin (RICCAR, 2017)

2.2.1. Forecasting of Temperature and Precipitation

According to the World Bank Climate Change Knowledge Portal, in the medium term (2050), while there is some disparity, there is overall agreement that Jordan will become warmer with more frequent heat waves and fewer frost days. It is anticipated that in in the eastern and southern areas of the Badia and in the northern and southern areas of the highlands, there is an increase in precipitation during the rainy season up to the year 2050, with a decrease for the rest of the country which could reach up to 50% in the North of Aqaba. The country will also become drier with projected trends indicating that the annual precipitation tends to decrease significantly with time. Rainfall intensity is expected to increase. Runoff (precipitation minus evapotranspiration, a measure of water availability) is projected to decrease.

Regarding the long-term projections (2100), the CORDEX RICCAR Initiative results (based on a broad range of global and regional climate and impact models) showed that climate pressures and their water sector impact will intensify over time with the decrease in water availability projected to get particularly severe after the year 2040. The Third National Communication on Climate Change (2014) using earlier RICCAR analysis suggest that by 2100 (end of century):

- Mean and maximum temperature will be 2-4°C higher for all Jordan;
- Precipitation will be 15-20 % lower and potential evapotranspiration about 150 mm higher.

The water sector will be the most heavily affected by climate change with anticipated consequences including:

- Reduced water availability;
- Less reliable seasonal rainfall;
- Increased intensity of droughts during which reservoirs are not refilled, groundwater is not recharged, and rain fed agriculture suffers damages;

- Increased intensity of flood events during which water and other infrastructure experiences overflows and damages; and
- Higher irrigation water demand because of higher evaporation due to increased temperature.

According to Rajsekhar and Gorelick (2017), Jordan, as a downstream nation dependent on transboundary river basins, is also extremely susceptible to the cascading impacts of climate change basins. For example, climate change in neighboring countries can have both a direct effect in Jordan due to diminishing river flow by lower rainfall in those countries, and an indirect effect of increasing irrigation demand due to drought.

USAID (2017) projected climate changes in Jordan to include:

- Rise in annual maximum temperature of up to 5.1°C and rise in annual minimum temperature of 3.8°C by 2085 (warming is stronger during the summer). Some models project temperatures to rise evenly across the country while others suggest the increase will be strongest in the eastern and southern regions.
- Increase in the frequency of heat waves.
- 10-day increase in the number of consecutive dry days from 2040–2070 (increase will be greatest in the southern Aqaba region).
- Precipitation projections are highly variable but point to an overall decrease between 15–60 percent from 2011 to 2099.

For Amman, some models suggest that by the end of the century, an increase in dry years (years with <200 mm precipitation) from once every three years to once every two years, about 30 days longer dry season, and a reduction in precipitation by ca. 10-15% (Abdulla, 2020).

Black (2009) used a regional climate model to investigate changes in Jordan and Israel precipitation at the end of the 21st century on daily to monthly timescales. The model predicted that this region will get significantly drier at the peak of the rainy season reflecting a reduction in both the frequency and duration of the rainy events. Chenoweth et al. (2011) conducted another simulation study for the period 2040-2099 and based on precipitation records (1961-1990) for the eastern Mediterranean and Middle East region, found that Jordan's precipitation will decrease by 17% in the middle of this century and by 21% at its end. Abdulla and Eshtawi (2015) studied the climate change impact on runoff, sediments and groundwater recharge for King Talal Dam watershed using the Soil and Water Assessment Tool (SWAT) model under different scenarios. The scenarios included: ±20% change in rainfall, and 1°C, 2°C and 3.5°C increases in average temperature. The study showed that climate warming can impact runoff, groundwater recharge and sediment yield in the Zarqa basin, which will also be greatly influenced by changes in rainfall volume.

A study by Hammouri (2009) aimed at the assessment of climate change impacts on water resources in Jordan through the selection of two sites for detailed study. These sites were Amman Zarqa basin and Yarmouk basin. The necessary meteorological data were collected and analyzed to study the current situation of the water resources with the selected sites. The Water Evaluation and Planning system (WEAP) was used to simulate surface runoff resulted from precipitation and taking into account the temperature values. The obtained results were calibrated and validated against measured runoff values. To assess the impact of climate change on water resources of the selected sites, 13 global circulation models (GCMs) were tested to select three models whose records are matching those of Jordan climate. The selected models were CSIROMK3, ECHAM5OM and HADGEM1. Simulation results obtained from base scenario and GCM scenarios were compared and it was found that the amounts of surface runoff resulted from precipitation will be highly affected by climate change. This will add another stress on the water resources of Jordan; knowing that the currently available resources suffer from the increasing demand as a result of demographic and limitation of these resources.

On another hand, Rajsekhar and Gorelick (2017) analyzed Jordan's surface water resources and agricultural water demand through 2100, considering the combined impacts of climate change and land-use change driven by the Syrian conflict (Figure *11*). They analyzed Jordan's surface water resources and agricultural water demand through 2100, considering the combined impacts of climate change and land-use change driven by the Syrian conflict. They use bias-corrected regional climate simulations as input to high-resolution hydrologic models to assess three drought types: meteorological (rainfall decrease), agricultural (soil moisture deficit), and hydrologic (streamflow decline) under future scenarios. The historical baseline period (1981–2010) is compared to the future (2011–2100), divided into three 30-year periods. Comparing the baseline period to 2070–2100, average temperature increases by 4.5°C, rainfall decreases by 30%, and multiple drought-type occurrences increase from ~8 in 30 years to ~25 in 30 years (Figure *12*). There is a significant increase in the contemporaneous occurrence of multiple drought types along with an 80% increase in simultaneous warm and dry events.

Since Azraq basin is one of the most important groundwater basins in Jordan, Al Qatarneh et al. (2018) used trend analysis using RClimDex for six rainfall stations and two metrological stations was performed to detect and predict climate change impacts on the Azraq basin until the year 2030. The results showed that monthly max value of daily mean temperature, tropical night, monthly maximum value of daily maximum temperature, monthly maximum value of daily minimum temperature and cool days were found to be statistically significant climate change indices. The trend of the max temperature during July is significant, while insignificant trend for the minimum temperature in the same month was noticed. The frequency of days in which the maximum temperature exceeded 38°C increased and there was increase in the minimum temperature count of values that are exceeding 20°C in the last 46 years. Regarding the rainfall, there is no change in total annual precipitation over the study area during the studied period. The results of simulating climate change impact into the evaporation showed expected increase by 4.74 and 5.32% for Al Butum and El Janab wadis, respectively, during the period of 2013–2030. Streamflow analysis showed slight decrease by 1.51 and 1.02% for both wadis, respectively.

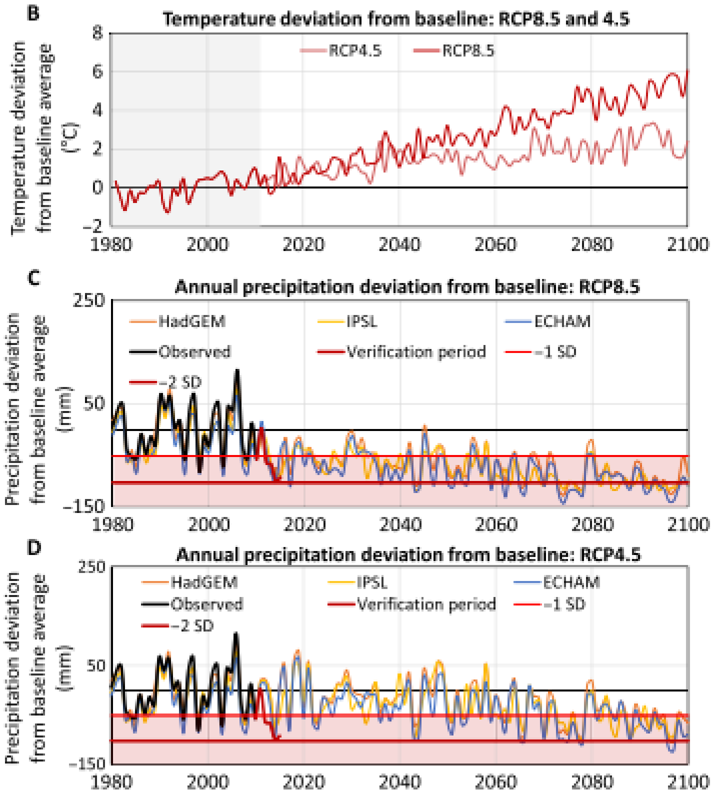


Figure 11: Projected Climate Change in Jordan. (B) Temperature Deviation from the Baseline Period Average (C) Annual Precipitation (D) Annual Precipitation Deviation from the Baseline Period Average for RCP4.5. (Rajsekhar and Gorelick, 2017)

Another study conducted by Abdulla (2020) investigated the climatic trends of the important climatic factors in Jordan mainly temperature and precipitation and developed the baseline scenarios (business as usual BAU) of the climate. Precipitation, maximum temperature, minimum temperature and mean temperature time series at selected eight climatic stations have been used to develop the BAU and the future climate scenarios in Jordan. Trend analysis revealed obvious decreasing trends in the precipitation time series of most of the stations, the decrease in precipitation started in the decade 1960's. While temperatures showed increasing trends, the minimum temperature has increased more than the maximum temperature. Climate baseline scenarios of the daily maximum temperature, minimum temperature, mean temperature and precipitation at the 8 locations in Jordan have been generated for the 55 years baseline period 1961 – 2014 using the NCEP re-analysis data, Hadley General Circulation Model (HadCM3) and the Statistical Downscaling Model (SDSM). Two scenario periods, the 2050-2065, and the 2080-2099 were considered. Recent projections of global climate changes in response to increasing greenhouse gas concentrations in the atmosphere include warming in Jordan from about 2.5°C to 5°C by end of century. All projection scenarios indicate a reduction in annual precipitation range from 10% to about 37%.

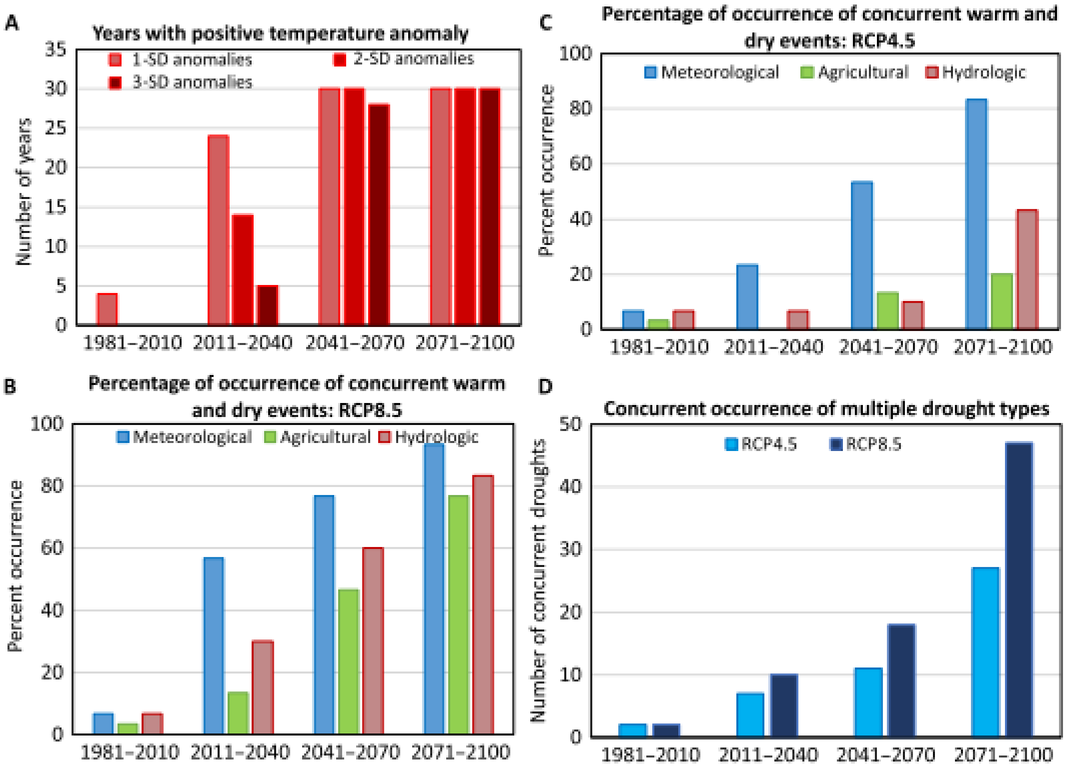


Figure 12: (A) Number of Years with a Positive Temperature Anomaly from the Baseline Period Average for RCP8.5. (B) Percent Chance of Occurrence of High Temperature and Different Drought Types for RCP8.5. (C) Percent Chance of Occurrence of High Temperature and Different Drought Types for RCP4.5. (D) Number of Events Resulting in Concurrent Occurrence of Multiple Drought Types for Each 30-year Time Slice (Rajsekhar and Gorelick, 2017)

In Jordan precipitation and flood flows have been measured and calculated for the last 6 decades witnessing precipitation amounts of all ranges of extremely low to extremely high precipitation amounts. This enabled Salameh and Abdallat (2020) to calculate flood runoff to precipitation ratios for many years. The historical record allows using the calculation of flood runoffs of the different catchment areas in Jordan for precipitation increases or decreases by 10% and 20%. The results show that for Jordan precipitation decrease by 10% and 20% will result in 26.2% and 52.8% decrease in flood flows and precipitation increase by 10% and 20% will result in 26.4% and 56.5% increase in flood flows. The arid areas, especially the arid highlands of south Jordan will be stronger affected by both increasing and decreasing precipitation than other areas. That can be explained by their low precipitation amounts and illustrates the vulnerability of these areas to climate change. 10% less precipitation will cause 26% reduction in surface water availability for the irrigation, which in the case of Jordan amounts to around 42 MCM/year. Irrigated agricultural production will reduce by the same percentage 8%. If precipitation decreases by 20% irrigation agricultural production will drop by 15.4%.

2.2.2. Forecasting of Sea Level Rise

SLR in general brings several consequences including coastal retreat leading to land area loss in area. This in turn could have serious economic and social consequences at local and national level as it affects all coastal establishments including tourism and recreational activities on beaches, industries, marinas, as well as ecosystems and biodiversity. The IPCC (2013) stated that certain coastal areas will experience more sea level increases than the open ocean. Specifically, for the Gulf of Aqaba, it is not easy predict SLR. There is no model today which accurately represents/models the anticipated and possible implications on the coastline, habitats and species (GEF/UNDP, 2014). With reference to Section 2.1.3 above, sea level in the Gulf of Aqaba is mainly controlled by remote wind stress on the Red Sea, internal waves generated at the Strait of Tiran and local sedimentation.

2.2.3. Climate Change Projections

The following table presents a summary of the impacts that climate change will have on several sectors in Jordan, as identified in the Third National Communication (GEF/UNDP, 2014). It shows the main messages that can be interpolated from the comprehensive climate change projections exercise conducted in the TNC (2014) report. The trends described below indicate the expected future of the climate in Jordan until 2100.

Table 3: Summary of sectoral climate change impacts in Jordan (GEF/UNDP, 2014)

Trend	Details
A warmer climate	All models converge that the temperature will increase. For the 2070-2100 period the average temperature could reach according to RCP 4.5 up to +2.1°C [+1.7°C to +3.2°C] and +4°C [3.8°C - 5.5°C] according to RCP8.5
A drier climate	Compared to the SNC that used CMPI3 results, CMPI5 results coupled with regional climate models in CORDEX give a more consistent trend towards a drier climate. In 2070-2100 the cumulated precipitation could decrease by 15% (- 6% to 25%) in RCP 4.5, by -21% (9% to - 35%) in RCP 8.5. The decrease would be more marked in the western part of the country.
Warmer summer, drier autumn, and winter	The warming would be more important in summer. The reduction in precipitation would be more important in winter and autumn than in spring, as for instance median value for precipitation decrease reaching - 35% in autumn of 2100
More heat waves	The analysis of summer temperatures monthly values and the inter-annual variability reveals that some thresholds could be exceeded. A pessimistic but possible projection for the summer months predicts that the average of maximum temperatures for the whole country could exceed 42-44°C
More drought, a contrasted water balance	The maximum number of consecutive dry days would increase in the reference model to more than 30 days for the 2070-2100 period. In contrast annual values still show possible heavy rainy years at the end of the century. More intense droughts would be (partly) compensated by rainy years in a context of a general decrease in precipitation. Evapotranspiration would increase. The occurrence of snow would strongly decrease. This will complicate water management.
No trend for intense precipitation or winds	The number of days with heavy rain (more than 10 mm) does not evolve significantly nor does the maximum wind speed or the direction of winds

3. Climate Risk Vulnerability Assessment

3.1. Introduction

The impacts of global climate change are increasingly being felt around the world. Rising temperatures, changing rainfall patterns, and the melting of glaciers and permafrost soils are affecting ecosystems and human societies in different ways. While climate change is expected to create new opportunities in some parts of the world, it is also expected to cause considerable distress. The extent of the impact depends on the magnitude of climatic changes affecting a particular system (exposure), the characteristics of the system (sensitivity), and the ability of people and ecosystems to deal with the resulting effects (adaptive capacities of the system). These three factors determine the vulnerability of the system.

Assessing vulnerability to climate change is important for defining the risks posed by climate change and provides information for identifying measures to adapt to climate change impacts. It enables practitioners and decision-makers to identify the most vulnerable areas, sectors, and social groups. In turn, this means climate change adaptation options targeted at specified contexts can be developed and implemented.

The methodology for undertaking a Climate Vulnerability and Risk Assessment (CVRA) can be summarized into three steps detailed below (Figure 13).

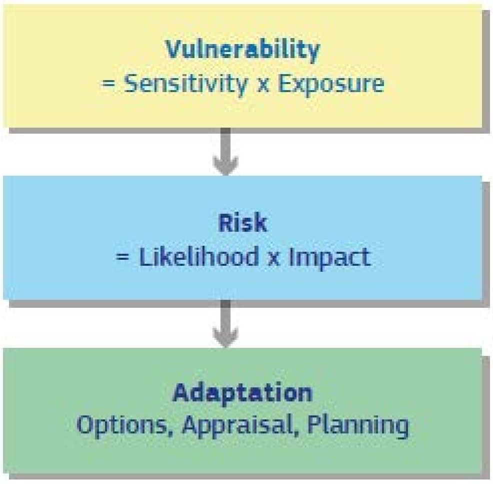


Figure 13: Main Steps in the Vulnerability and Risk Assessment

Details of each of these steps/tasks are as such:

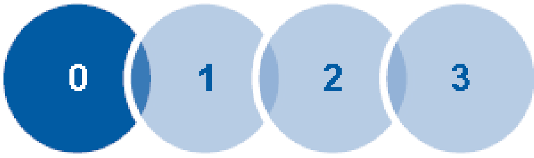
- **Task 1: Vulnerability:** considers which climate hazards the project is most vulnerable to as a result of its components and location;
- **Task 2: Risk:** considers the probability and severity of climate risks affecting the project;
- **Task 3: Adaptation:** Intends to identify and appraise adaptation options and integrate the most suitable measures into the project, with the aim of increasing the project's resilience and adapting to climate change.

The above tasks can be optionally preceded by **Task 0 Preparation.** The aim of this pre-task is to set the foundations for the assessment, understanding the background of the project, how the methodology will be undertaken and who should be involved. Establishing this information at the outset will mean that the assessment is adequately scoped and fit for purpose (Figure *14*).

Figure 14: Climate Risk and Vulnerability Assessment Stages

3.2. Task 0-Preparation

The aim of this task to set the foundations for the assessment and ensure that it is adequately scoped.



First it is important to have a good understanding of the proposed project and its objective, including all ancillary activities necessary to support the project's development and operation.

According to the Terms of Reference (ToR), this project will treat abstracted seawater through reverse osmosis (RO) and convey desalinated water from the Gulf of Aqaba, providing potable water to Aqaba, Amman and other cities along the pipeline route.

The AAWDCP will provide 300 million cubic meters per year (MCM/year) of potable water to meet the 2025 projected water demand.

The project is divided into the following principal project components (CDM Smith/USAID, 2020):

- Marine works: This component consists of the intake and outfall systems, including seawater intake towers, pipelines to convey the seawater to the intake pump station (IPS), IPS (including screens), and pipeline(s) to convey seawater to the RO desalination plant. The marine works include a brine reservoir at the desalination plant and brine pipelines to convey the brine from the brine reservoir through to the hydropower generation system to the outfall discharge diffusers in the Gulf of Aqaba.
- RO Desalination plant: This consists of the facilities to produce desalinated water, including pretreatment, reverse osmosis (RO), energy recovery, post-treatment, and disinfection with delivery of the desalinated water to the upstream flanges at the treated water reservoirs. The plant includes all associated chemical storage and dosing systems, water treatment facilities and structures and associated civil works, support facilities, mechanical equipment, piping and valves, instrumentation and control (I&C) for the marine works, desalination plant, and associated electrical systems.
- Conveyance pipeline from the RO desalination plant to the existing Abu Alanda and Al Muntazah Reservoirs: this consists of all works associated with approximately 420 kilometers (km) of pipeline downstream of the treated water reservoirs at the desalination plant and up to the delivery points at the existing Abu Alanda and Al Muntazah Reservoirs. The pipeline diameter will range from 84 to 90 inches along the pipeline route and a series of pump stations will pump the treated water from an

elevation of about 100 meters (m) to an elevation of 985 m as shown in Figure *15*.

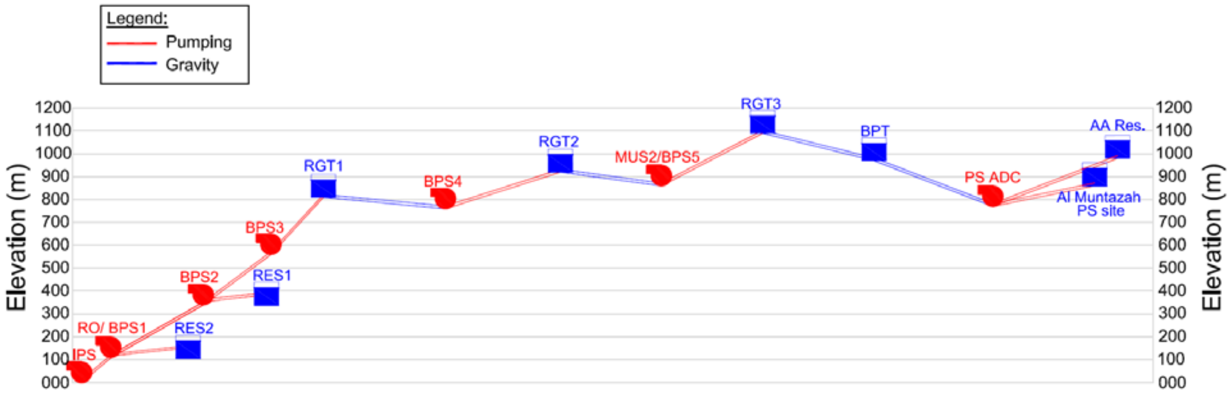
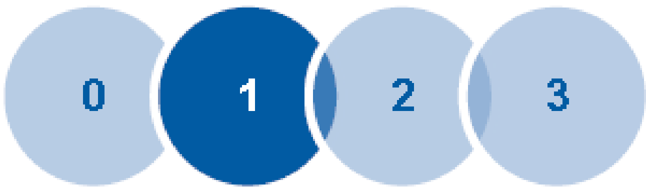


Figure 15: Schematic Profile of AAWDCP

- Pump stations and reservoirs along the conveyance system pipeline: These include the treated water reservoir and the initial treated water high-pressure pump station (BPS1) after the RO desalination plant, five subsequent pressure re-boosting stations (BPS2, BPS3, BPS4, Mudawarra PS [MUS2/BPSS], Abu Alanda PS [PS AA]), and five intermediate reservoirs (RGT1, RGT2, RGT3, BPT), including all associated civil works, support facilities, mechanical equipment, piping and valves, I&C, and low-voltage electrical systems.

3.3. Task 1-Sensitivity/Vulnerability Assessment

The aim of this task is to understand which climate hazards the project may be vulnerable to, and to screen hazards in or out of the more detailed risk assessment.



Vulnerability of a project is a combination of two aspects: 1) how sensitive the project's components are to climate hazards (sensitivity) and, 2) the probability of these hazards occurring at the project location now and in the future (exposure). These two aspects can be assessed in detail separately or considered in combination. The order of these two sub-tasks depends on when in the project development cycle the assessment is undertaken, in reality they will often be done in parallel. If the location of the project is already known then some site specific climate hazards can already be ruled in or out of exposure, whilst if the technology of the project is already selected some of the specific climate hazards can be considered relevant or not in terms of the sensitivity analysis.

Sensitivity x Exposure = Vulnerability

According to the ToR, the AAWDC Project concept involves the development of infrastructure, to be located entirely on the territory of Jordan, starting from the Southern Red Sea coast in Aqaba at the industrial zone and ending in the capital city of Amman. The project entails:

- Abstracting and pumping seawater from the Southern Jordanian part of the Gulf of Aqaba, Red Sea in the vicinity of the Phosphate Mines Company Industrial Complex.
- Desalinating seawater in Aqaba (300 MCM/year).
- Transferring brine effluent back to the Gulf of Aqaba.
- Delivering freshwater (250 MCM/year) to Aqaba, Amman and other governorates via a main conveyor pipeline, lateral collection pipelines and a series of booster pump stations and regulating tanks. The destination of the remaining 50 MCM/year is yet to be decided.

When considering a changing climate, the key changes are seen in the following climatic factors (these are also referred to as primary climate drivers):

- **Temperature** – changes in average temperatures and the frequency and magnitude of extreme temperatures;
- **Precipitation** (rain, snow, etc.) – changes in average precipitation and the frequency and magnitude of extreme precipitation events;
- **Sea level** – change in relative sea level;
- **Wind speeds** – changes in average wind speeds and maximum wind speeds;
- **Humidity** – changes in the amount of water vapour in the atmosphere; and
- **Solar radiation** – changes in the energy from the sun

3.3.1. Identification of the potential climate-related hazards

The sensitivity of the project should be determined in relation to a range of climate hazards. The following table presents a short description of each one of the climate hazards as well as the climate related hazards which will be considered for the specific project.

Table 4: Identification of Climate-Related Hazards

No.	Hazard	Description	Relevant to project
1	Average air temperature increase	Increases in average temperatures over time	√
2	Extreme temperature increase and heat waves	Changes in the frequency and intensity of periods of high temperatures, including heat waves (periods of extremely high maximum and minimum temperatures)	√
3	Average rainfall change	Trends over time of either more or less precipitation (rain, snow, hail, etc.)	
4	Extreme rainfall change	Changes in the frequency and intensity of periods of intense rainfall or other precipitation	√
5	Water availability	The relative abundance or lack of water	√
6	Water temperature	Changes in the temperature of surface and ground water	
7	Flooding (coastal and fluvial)	Flooding from the sea or from rivers	√
8	Seawater temperature	Changes in the average sea surface water temperature	√
9	Relative sea level rise	Caused by a combination of increased sea temperatures (expanding the volume of water) and melting ice sheets and glaciers	√
10	Storm surges	An abnormal rise of seawater generated by a storm, over and above the predicted astronomical tides	√
11	Saline intrusion	Movement of salt water into freshwater aquifers, which can lead to contamination of drinking water sources and other consequences	√
12	Ocean salinity	Changes in the concentrations of salt in seawater	√
13	Ocean pH	Acidification of the oceans	√
14	Coastal erosion	The wearing away of land and the removal of beach or dune sediments by wave action, tidal currents, wave currents, drainage or high winds	√
15	Soil erosion	The process of removal and transport of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, winds and underground water	√
16	Ground instability/	Landslide: A mass of material that has slipped	

No.	Hazard	Description	Relevant to project
	landslides/ avalanche	downhill by gravity, often assisted by water when the material is saturated	
17	Soil salinity	Changes in the salt content in the soil	
18	Average wind speed	Changes in average wind speeds over time	√
19	Maximum wind speed	Increases in the maximum force of gusts of wind	√
20	Storms (tracks & intensity)	Changes in the location of storms, their frequency and intensity	
21	Humidity	Changes in the amount of water vapour in the atmosphere	
22	Droughts	Prolonged periods of abnormally low rainfall, leading to shortages of water	√
23	Dust Storms	A storm of strong winds and dust-filled air	
24	Wild fire	Unwanted, unplanned and damaging fires such as forest fires and fires of shrub and grasslands	
25	Air quality	Increased concentrations of pollutants locally, including incidents such as smog	√
26	Urban heat island effect	Cities or metropolitan areas which are significantly warmer than the surrounding rural area, caused by higher absorption of solar energy by materials in the urban area, such as asphalt	
27	Growing season length	Changes in the seasons during which certain flora species grow, either longer or shorter	
28	Solar radiation	The energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy	
29	Cold spells	Prolonged periods of extremely cold temperatures	√
30	Freeze-thaw damage	Repeated freezing and thawing may cause stress damage to structure such as concrete	
31	Melting permafrost	Melting of previously permanently frozen soil	

The grey highlighted cells in the table above correspond to the climate hazards which are relevant for the AAWDC project.

3.3.2. Sensitivity analysis

Different types of projects are susceptible to different climate hazards. Based on the information gathered in task 0 about the project context, it is possible to understand how the project functions, how critical the project is within its wider network or system, and therefore which hazards are most relevant and why.

The sensitivity of the project options to climate related hazards should be assessed through the lens of the four key themes encompassing the main components of the project as follows:

- Marine works (intake towers and pipelines, outfall pipeline and diffuser manifold) and near shore IPS.
- Desalination Plant.
- Conveyance pipeline from the desalination plant to the existing reservoirs.
- Pump stations and reservoirs along the conveyance system pipeline
- The sensitivity analysis has been implemented through the following steps:

- The components of the project have been determined and are presented under the column *sensitivity component*. These are the marine works, the desalination plant, the conveyance pipeline from the desalination plant to the existing reservoirs; and the pump stations and reservoirs along the conveyance system pipeline.
- The climate related hazards which have been determined in Table 4.
- Sensitivity ranking has been undertaken separately for each one of the various elements of the project in a scale of high, medium, and low sensitivity, respectively, through expert's judgment.

The summarized results of the sensitivity analysis are presented in Table 5.

Table 5: Sensitivity Matrix for AAWDCP

	Climate Related Hazards[3]																	
Sensitivity Component	Average air temperature increase (1)	Extreme temperature occurrences (including heat waves) (2)	Extreme rainfall events (4)	Water availability (5)	Flooding (coastal and fluvial) (7)	Seawater temperature (8)	Relative sea level rise (9)	Storm surges (10)	Saline intrusion (11)	Ocean salinity (12)	Ocean pH (13)	Coastal erosion (14)	Soil erosion (15)	Average wind speed (18)	Maximum wind speed (19)	Droughts (22)	Air quality (25)	Cold spells (29)
Marine works	Low	Low	Low	Low	Medium	Medium	Low	Medium	Low	Medium	Medium	Low	Low	Low	Low	Low	Low	Low
Desalination plant	Medium	Medium	Low	High	High	Low	High	Medium	Low	Low	Medium	Low	Medium	Low	Low	Medium	High	Low
Pipeline	High	High	Low	Low	High	Low	Low	Low	Low	Low	Low	High	High	Low	Low	Low	Low	Low
Pump stations and reservoirs	Medium	Medium	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	Low	Low

Climate sensitivity	LOW	MEDIUM	HIGH

Note:
High sensitivity: Climate variable/hazard may have significant impact on assets and processes, inputs, outputs and transport links.
Medium sensitivity: Climate variable/hazard may have slight impact on assets and processes, inputs, outputs and transport links.
Low sensitivity: Climate variable/hazard has no effect.

[3] The number between parenthesis refers to the climate hazard that might affect the project as listed in Table 4.

The following tables present explanation for the justification of sensitivity ranking for each one of the four components of the project.

Table 6: Sensitivity Matrix for Marine Works

Climate Hazard	Sensitivity	Explanation
Average air temperature increase	LOW	N/A
Extreme temperature occurrences (including heat waves)	LOW	
Extreme rainfall events	LOW	Intense rainfalls cause interruption of power supply. Service capacity may be reduced or halted.
Water availability	LOW	Leakage from pipes that carry highly concentrated brine out of the plant may percolate underground and cause damage to groundwater aquifers depending on local geological conditions.
Flooding	MEDIUM	Pipelines may be damaged during a flood event.
Seawater temperature	MEDIUM	Increased temperatures reduce the level of dissolved oxygen (DO) in seawater. Significant drop in DO levels can be toxic to certain marine species. Thermal pollution increases bacterial and aquatic invertebrate activity which in turn will diminish already lowered DO. The temperature of the brine water effluent resulting from thermal desalination processes is typically around 1°C above the feed water temperature.
Relative sea level rise	LOW	A significant rise in sea level, especially combined with high tides and storm surge could result in sea water ingress to the intake pumping station electrical component.
Storm surges	MEDIUM	Storm intensities and frequencies will change as a result of climate change causing increased extreme water levels and wave heights. This could affect the integrity of submerged pipelines that might be drifted away by strong currents unless effectively laid and anchored on the seabed.
Saline intrusion	LOW	N/A
Ocean salinity	MEDIUM	Concentrate (brine) discharge is high in salinity and may contain low concentrations of chemicals. These properties of concentrate can adversely affect the marine habitats and receiving water environment unless properly diluted and process chemicals are either prevented or removed prior discharge.
Ocean pH	MEDIUM	Conditioning with sulphuric acid (H2SO4) to pH 6.5-7 and dosing of coagulant aids (polymers) can enhance the coagulation process (in SWRO pre-treatment) and was common in the past but tend to be avoided in the last years. The environmental concern relative to the use of sulfuric acid for pH adjustment in the pre-treatment process is that it reduces the alkalinity and pH of the brine, which subsequently may affect the alkalinity and pH at the area of discharge. Despite the fact that open sea is a natural system with high buffering capacities that can accommodate the impacts resulted by acidic discharges, still the long-term impact of alkalinity reduction of discharges to local marine species is unknown particularly for a very rich coral area. The acid dose before RO treatment envisaged by the project is low. pH at the discharge site may be also affected when acidic or basic solutions used for membranes cleaning are mixed with the brine without prior neutralisation. When cleaning additives are used (EDTA, biocides, detergents, other

Climate Hazard	Sensitivity	Explanation
		proprietary chemicals), or organic chemicals (e.g., acetic acid) are used, the generated spent CIP cleaning effluents cannot be fully neutralised.
Coastal erosion	LOW	N/A
Soil erosion	LOW	N/A
Average wind speed	LOW	The design of brine outlets was based on 'still' conditions which is the worst-case scenario in terms of achieved dilutions. Currents will further enhance brine dilution. Submerged structure will be affected in the presence of strong currents.
Maximum wind speed	LOW	
Drought	LOW	N/A.
Air quality	LOW	N/A.
Cold spells	LOW	The equipment inside the intake structure is vulnerable to extreme cold temperatures.

Table 7: Sensitivity Matrix for Desalination Plant

Climate Hazard	Sensitivity	Explanation
Average air temperature increase	MEDIUM	Additional future amount for urban water demand would be needed with its associated costs (financial, socio-economic, and environmental).
Extreme temperature occurrences (including heat waves)	MEDIUM	
Extreme rainfall events	LOW	Intense rainfalls may cause interruption of power supply. Service capacity may be reduced or halted.
Water availability	HIGH	Increase in water demand can affect the process and the general site management.
Flooding	HIGH	Increase in storms and flooding could: (i) Lead to damage to buildings and site closure, (ii) Lead to increased incidences of runoff litter and debris, and (iii) Lead to change in the cost and availability of insurance cover.
Seawater temperature	LOW	Operating SWRO at elevated temperatures creates an increased risk of fouling of the RO membrane
Relative sea level rise	HIGH	Desalination plants are energy intensive facilities whose electricity use could result in significant volumes of greenhouse gas emissions, thereby contributing to climate change impacts such as ocean acidification and habitat loss due to sea level rise.
Storm surges	MEDIUM	Storm intensities and frequencies will change as a result of climate change causing increased extreme water levels storm damage, risk of flooding from surrounding wadis and defense failure.
Saline intrusion	LOW	N/A
Ocean salinity	LOW	Concentrates discharge are high in salinity and may contain low concentrations of chemicals. These properties of concentrate can pose problems for the marine habitats and receiving water environments.
Ocean pH	MEDIUM	Conditioning with sulphuric acid (H_2SO_4) to pH 6.5-7 and dosing of coagulant aids (polymers) can enhance the coagulation process (in SWRO pre-treatment) and was common in the past but tend to be avoided in the last years. The environmental concern relative to the use of sulfuric acid for pH adjustment in the pre-treatment process

Climate Hazard	Sensitivity	Explanation
		is that it reduces the alkalinity and pH of the brine, which subsequently may affect the alkalinity. and pH at the area of discharge. Despite the fact that open sea is a natural system with high buffering capacities that can accommodate the impacts resulted by acidic discharges, still the long-term impact of alkalinity reduction of discharges to local marine species is unknown particularly for a very rich coral area. The acid dose before RO treatment envisaged by the project is low. pH at the discharge site may be also affected when acidic or basic solutions used for membranes cleaning are mixed with the brine without prior neutralisation. When cleaning additives are used (EDTA, biocides, detergents, other proprietary chemicals), or organic chemicals (e.g., acetic acid) are used, the generated spent CIP cleaning effluents cannot be fully neutralised.
Coastal erosion	LOW	N/A
Soil erosion	MEDIUM	Soil erosion from earthworks can cause sediment discharge to waterways affecting aquatic flora and fauna unless properly managed.
Average wind speed	LOW	N/A.
Maximum wind speed	LOW	Wind power, if used to generate energy, could contribute to the reduction of greenhouse gases but would also stabilize electricity cost.
Droughts	MEDIUM	Frequent and intense periods of drought will impact the ability to accommodate growth, meet the needs of water users, and provide essential municipal operations and services.
Air quality	HIGH	The increased energy consumption indirectly contributes to air emissions from power generating plants. These air pollutants can have a harmful impact on public health.
Cold spells	LOW	N/A

Table 8: Sensitivity Matrix for Conveyance Pipeline

Climate Hazard	Sensitivity	Explanation
Average air temperature increase	HIGH	High temperature degrades materials used in infrastructure and equipment. Infrastructure and equipment aging may be accelerated. This may require more frequent repair and higher maintenance budgets.
Extreme temperature occurrences (including heat waves)	HIGH	
Extreme rainfall events	LOW	Intense rainfalls may cause interruption of power supply. Service capacity may be reduced or halted.
Water availability	LOW	N/A
Flooding	HIGH	The proposed AAWDC pipeline will cross the main Wadi Yutum Interchange and will pass along its wadi bank for approximately 5km (Figure 8). Despite the reduction in peak flow rates that the flood attenuation dams might achieve, the flood risk for the purpose of this study is still considered high
Seawater temperature	LOW	N/A
Relative sea level rise	LOW	N/A

Climate Hazard	Sensitivity	Explanation
Storm surges	LOW	Flooding at entry points in the distribution system, such as the air release blow-off valves.
Saline intrusion	LOW	N/A
Ocean salinity	LOW	N/A
Ocean pH	LOW	N/A
Coastal erosion	HIGH	Coastal erosion can lead to damage of transmission pipeline system.
Soil erosion	HIGH	Soil erosion can lead to damage of water transmission system.
Average wind speed	LOW	Wind speed changes can cause SCADA disruption due to antenna damage.
Maximum wind speed	LOW	Maximum wind speed can cause SCADA disruption due to antenna damage.
Drought	LOW	N/A
Air quality	LOW	N/A
Cold spells	LOW	Pipes or joints may be damaged due to soil freezing. Pipes may crack or joints may leak, leading to water loss. Infrastructure may require more frequent repair and higher maintenance budgets.

Table 9: Sensitivity Matrix for Pumping Stations and Reservoirs

Climate Hazard	Sensitivity	Explanation
Average air temperature increase	MEDIUM	High temperature degrades materials used in infrastructure and equipment of pumping stations. Infrastructure and equipment aging may be accelerated. This may require more frequent repair and higher maintenance budgets.
Extreme temperature occurrences (including heat waves)	MEDIUM	
Extreme rainfall events	MEDIUM	Extended loss of power supply at the pumping stations, equipment inoperability.
Water availability	LOW	N/A
Flooding	MEDIUM	Street flooding following a rain event may inundate pump stations and damage electrical equipment.
Seawater temperature	LOW	N/A.
Relative sea level rise	LOW	N/A.
Storm surges	LOW	Equipment may be damaged or lost during a storm surge. event.
Saline intrusion	LOW	N/A
Ocean salinity	LOW	N/A
Ocean pH	LOW	N/A
Coastal erosion	LOW	N/A
Soil erosion	MEDIUM	The absence of vegetation increases the risk of soil erosion and flash floods and landslides.

Climate Hazard	Sensitivity	Explanation
Average wind speed	LOW	Wind speed changes can cause SCADA disruption due to antenna damage.
Maximum wind speed	LOW	Maximum wind speed can cause SCADA disruption due to antenna damage.
Droughts	LOW	N/A
Air quality	LOW	N/A
Cold spells	LOW	The buildings and facilities most vulnerable to extreme winter storms include those that have functions and equipment that could be impacted by corresponding cold temperatures.

3.3.2.1. Evaluation of exposure to climate related hazards

Once the sensitivities of the project have been identified, the next step is to evaluate exposure of the project and its assets to climate hazards in the locations where the project will be implemented for the baseline climate conditions and the future climate conditions.

Table *10* below presents the exposure of the project to baseline and future climate and Table 11 comprises the respective justification relative to exposure assessment.

3.3.2.2. Assessment of exposure to baseline and future climate

Table 10: Assess Exposure to Current and Future Climate for the AAWDCP

	Climate Related Hazards[4]																	
Exposure Table	Average air temperature increase (1)	Extreme temperature occurrences (including heat waves) (2)	Extreme rainfall events (4)	Water availability (5)	Flooding (coastal and fluvial) (7)	Seawater temperature (8)	Relative sea level rise (9)	Storm surges (10)	Saline intrusion (11)	Ocean salinity (12)	Ocean pH (13)	Coastal erosion (14)	Soil erosion (15)	Average wind speed (18)	Maximum wind speed (19)	Droughts (22)	Air quality (25)	Cold spells (29)
Exposure to current climate	MEDIUM	MEDIUM	MEDIUM	MEDIUM	HIGH	LOW	LOW	LOW	LOW	MEDIUM	LOW	MEDIUM	MEDIUM	LOW	LOW	MEDIUM	MEDIUM	LOW
Exposure to future climate	MEDIUM	MEDIUM	MEDIUM	MEDIUM	HIGH	LOW	LOW	LOW	LOW	MEDIUM	LOW	MEDIUM	MEDIUM	LOW	LOW	MEDIUM	MEDIUM	LOW
Highest score, current +future	MEDIUM	MEDIUM	MEDIUM	MEDIUM	HIGH	LOW	LOW	LOW	LOW	MEDIUM	LOW	MEDIUM	MEDIUM	LOW	LOW	MEDIUM	MEDIUM	LOW

Climate sensitivity	LOW	MEDIUM	HIGH

Note:
High sensitivity: Climate variable/hazard may have significant impact on assets and processes, inputs, outputs and transport links.

[4] The number between parenthesis refers to the climate hazard that might affect the project as listed in Table 4.

Medium sensitivity: Climate variable/hazard may have slight impact on assets and processes, inputs, outputs and transport links.
Low sensitivity: Climate variable/hazard has no effect.

Table 11: Justification for Exposure to Baseline and Future Climate for AAWDCP

Climate variables and hazards	Ranking for Exposure to baseline	Ranking for Exposure to future climate	Explanation
Average air temperature increase	MEDIUM	MEDIUM	For the 2070-2100 period the average temperature could reach according to RCP 4.5 up to +2.1 °C [+1.7 °C to +3.2°C] and +4°C [3.8 °C -5.5 °C] according to RCP8.5.
Extreme temperature occurrences (including heat waves)	MEDIUM	MEDIUM	The trend for extreme temperature increase follows the same profile as the mean temperature.
Extreme rainfall change	MEDIUM	MEDIUM	In 2070-2100 the cumulated precipitation could decrease by 15% (-6% to 25%) in RCP 4.5, by -21% (9% to - 35%) in RCP 8.5.
Water availability	MEDIUM	MEDIUM	Reduced rainfall, which in combination with temperature increase, results in a reduction in water reserves.
Flooding	HIGH	HIGH	Although reduced rainfall will decrease the frequency of flooding in the country, the project area belongs to a flooding zone and the exposure of the project characterized as high (current and future) according to UNWFP (2019) study (Figure 8 refers).
Seawater temperature	LOW	LOW	The Project will not have any impact on the seawater temperature. Reject brine will be discharged back in the sea at around ambient seawater temperature. No increase in seawater temperature of the Gulf of Aqaba has been firmly reported. In the contrary, several articles indicate high resilience of the Red Sea and Gulf of Aqaba to climate change impacts. Even if some mild increase in seawater temperature occurs due to climate change its impact on the Project will be minimal.
Relative sea level rise	LOW	LOW	Sea level rise is not expected to occur at the Gulf of Aqaba, which makes sea level rise consequences of coastal retreat and land area loss minimal. Sea level in the Gulf of Aqaba has historically been and most likely will continue to be determined by remote wind forcing, which are unlikely to significantly change.
Storm surges	LOW	LOW	According to Drews (2015) (Figure 9 refers) the project area does not belong to a storm surge zone.
Saline intrusion	LOW	LOW	The only risk of saline intrusion to groundwater table might be related to the discharged brine. This however is carefully considered in the design.

Climate variables and hazards	Ranking for Exposure to baseline	Ranking for Exposure to future climate	Explanation
Ocean salinity	MEDIUM	MEDIUM	Waters of the Gulf of Aqaba are in balance with the Red Sea water by exchange through the Tiran Strait. Upper water in the Gulf of Aqaba is already higher in salinity than the Red Sea water. Brine discharge will result in localized small elevation in salinity (i.e., 2% above ambient within 100m from the diffusers) which dissipates rapidly in the Gulf of Aqaba for its remarkable depth and ultimately balances with the Red Sea. No significant salinity build-up is expected. However, exposure assessment, precautionary, is considered medium.
Ocean pH	LOW	LOW	The rapid increase of atmospheric CO2 has caused oceans and seas to absorb increasingly greater amounts of CO2. This process disturbs the pre-existing chemical equilibrium of the sea, resulting in seas changing their chemical state and altering the ocean pH. By 2100, under medium emissions scenarios, ocean pH is projected to decrease by 0.3 pH units from levels 100 years ago. Hence this parameter has minor effect in the present and future climate.
Coastal erosion	MEDIUM	MEDIUM	Sea level rise in the Gulf of Aqaba is unlikely to happen. However, a precautionary medium exposure assessment is given.
Soil erosion	MEDIUM	MEDIUM	Increased temperature, prolonged droughts lead to desertification and soil erosion.
Average wind speed	LOW	LOW	The average wind speed or the direction of winds in the area are not expected to change significantly in the present or in the future climate.
Maximum wind speed	LOW	LOW	According to future projections, no significant change in maximum wind speed is expected.
Droughts	MEDIUM	MEDIUM	The maximum number of consecutive dry days would increase to more than 30 days for the 2070-2100 period. Exposure to drought will not have direct impact on the Project. However, it will result in a stronger need for recycled and desalinated water. As Jordan has no marine resources other than the Gulf of Aqaba, more projects might need to be built on the limited and already crowded coastal area in Aqaba.
Air quality	MEDIUM	MEDIUM	The Project involves dramatic energy consumption and consequently significant emissions at power stations to a level that may affect the air quality.
Cold spells	LOW	LOW	According to the forecasting scenarios argument, cold spells are not predicted to increase (baseline and future).

3.3.3. Vulnerability assessment

Vulnerability (V) is calculated as follows:

V=S x E

where S is the degree of sensitivity that asset has, and E is exposure to baseline climate conditions/secondary effects.

The following table presents the vulnerability classification matrix of each climate related hazard which could impact the project both for baseline and future climate and for each one of the four components themes (Marine works, Desalination plant, Pipeline, Reservoirs and pumping stations). It should be noted that climate related hazards that are not applicable for each component of the project (Table 4 refers) are not included in the below vulnerability classification matrixes.

The following tables illustrate vulnerability analysis for each theme for baseline and future climate.

Table 12: Vulnerability Classification Matrix for the Marine Works-Baseline Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	9,15,18,19,29	1,2,4,5,11,14,22,25	
	Medium	8,12,13	10	7
	High			

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

Table 13: Vulnerability Classification Matrix for the Marine Works-Future Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	9,15,18,19,29	1,2,4,5,11,14,22,25	
	Medium	8,12,13	10	7
	High			

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

Table 14: Vulnerability Classification Matrix for the Marine Works-Baseline + Future Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	9,15,18,19,29	1,2,4,5,11,14,22,25	
	Medium	8,12,13	10	7
	High			

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

Table 15: Vulnerability Classification Matrix for the Desalination Plant-Baseline Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,18,19,29	4,11,14	9
	Medium	13,15	1,2,10,22	
	High		5,25	7

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

Table 16: Vulnerability Classification Matrix for the Desalination Plant-Future Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,18,19,29	4,11,14	9
	Medium	13,15	1,2,10,22	
	High		5,25	7

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

Table 17: Vulnerability Classification Matrix for the Desalination Plant-Baseline + Future Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,18,19,29	4,11,14	9
	Medium	13,15	1,2,10,22	
	High		5,25	7

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

Table 18: Vulnerability Classification Matrix for the Pipeline-Baseline Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,13,18,19,29	4,5,10,11,22,25	
	Medium			
	High	15	1,2,14	7

Vulnerability level

Colour	Level
Green	Low
Orange	Medium
Red	High

Table 19: Vulnerability Classification Matrix for the Pipeline-Future Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,13,18,19,29	4,5,10,11,22,25	
	Medium			
	High	15	1,2,14	7

Vulnerability level

Colour	Level
Green	Low
Orange	Medium
Red	High

Table 20: Vulnerability Classification Matrix for the Pipeline-Baseline + Future Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,13,18,19,29	4,5,10,11,22,25	
	Medium			
	High	15	1,2,14	7

Vulnerability level

Colour	Level
Green	Low
Orange	Medium
Red	High

Table 21: Vulnerability Classification Matrix for the Reservoirs and Pumping Stations-Baseline Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,13,18,19,29	5,10,11,14,22,25	
	Medium	15	1,2,4	7
	High			

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

Table 22: Vulnerability Classification Matrix for the Reservoirs and Pumping Stations-Future Climate

Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,13,18,19,29	5,10,11,14,22,25	
	Medium	15	1,2,4	7
	High			

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

Table 23: Vulnerability Classification Matrix for the Reservoirs and Pumping Stations-Baseline + Future Climate

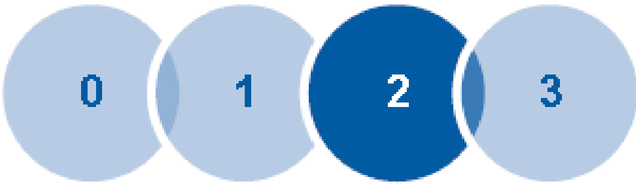
Sensitivity	Assessment	Exposure		
		Low	Medium	High
	Low	8,9,12,13,18,29	5,10,11,14,22,25	
	Medium	15	1,2,4	7
	High			

Vulnerability level

(green)	Low
(orange)	Medium
(red)	High

3.4. Task 2-Risk Assessment

The aim of this task is to consider the likelihood and severity of each risk affecting the success of the project.



The risk will be assessed considering the following formula.

Probability x Severity = Risk

3.4.1. Probability (Likelihood analysis)

This part of the risk assessment looks at how likely the identified climate hazards are to occur within a given timescale (the lifetime of the project). The scale which used for the specific analysis are a scale of 5 levels (Rare, Unlikely, Moderate, Likely and Almost certain). Table 24 below presents the scoring scale for assessing the likelihood of each climate hazard and respective risk definitions.

Table 24: Scale for Assessing the Probability of Hazards Affecting the Project

1	2	3	4	5
Rare	**Unlikely**	**Possible**	**Likely**	**Almost Certain**
Highly unlikely to occur	Given current practices and procedures, this incident is unlikely to occur	Incident has occurred in a similar country / setting	Incident is likely to occur	Incident is very likely to occur, possibly several times
5% chance of occurring	20% chance of occurring	50% chance of occurring	80% chance of occurring	95% chance of occurring

For the implementation of the above Risk Assessment Matrix for the four components of the project, the essential climate related hazards which should be further examined regards probability, are those with a high or medium vulnerability level and more specific the following:

- For the component of Marine works the following are examined: Average air temperature increase (1), Extreme temperature occurrences (including heat waves) (2), Extreme rainfall events (4), Water availability (5), Flooding (coastal and fluvial) (7), Seawater temperature (8), Storm surges (10), Saline intrusion (11), Ocean salinity (12), Ocean pH (13), Coastal erosion (14), Droughts (22), Air quality (25).
- For the component of Desalination plant the following are examined: Average air temperature increase (1), Extreme temperature occurrences (including heat waves) (2), Extreme rainfall events (4), Water availability (5), Flooding (coastal and fluvial) (7), Storm surges (10), Saline intrusion (11), Ocean pH (13), Coastal erosion (14), Soil erosion (15), Droughts (22), Air quality (25).
- For the component of Pipeline the following are examined: Average air temperature increase (1), Extreme temperature occurrences (including heat waves) (2), Extreme rainfall events (4), Water Availability (5), Flooding (coastal and fluvial) (7), Storm surges (10), Saline intrusion (11), Coastal erosion (14), Soil erosion (15), Droughts (22), Air quality (25).
- For the component of Reservoirs and pumping stations the following are examined: Average air temperature increase (1), Extreme temperature occurrences (including heat waves) (2), Extreme rainfall change (4), Water Availability (5), Flooding (coastal and fluvial) (7), Storm surges (10), Saline intrusion (11), Coastal erosion (14), Soil erosion (15), Droughts (22), Air quality (25).

The probability of each one of the climate related hazards for each theme are presented in Table 25.

Table 25: Probability Ranking for All the Components of the Project

Project Type	Probability	Average air temperature increase (1)	Extreme temperature occurrences (including heat waves) (2)	Extreme rainfall events (4)	Water availability (5)	Flooding (coastal and fluvial) (7)	Seawater temperature (8)	Relative sea level rise (9)	Storm surges (10)	Saline intrusion (11)	Ocean salinity (12)	Ocean pH (13)	Coastal erosion (14)	Soil erosion (15)	Average wind speed (18)	Maximum wind speed (19)	Droughts (22)	Air quality (25)	Cold spells (29)
AAWDCP	Marine works																		
	Desalination plant																		
	Pipeline																		
	Pump stations and reservoirs																		

(Table 25 header: Climate Related Hazards[5])

Justification for the probability ranking per climate related hazard is presented in Table *26* and Table 27.

Table 26: Justification for Probability Ranking for Marine Works and Desalination Plant

Climate variables and hazards	Probability ranking for Marine Works	Probability ranking for Desalination Plant	Explanation
Average air temperature increase	Almost certain	Almost certain	Marine works and desalination plants contain a lot of confined spaces. Workers must enter those confined spaces to carry out some tasks such as removing fouling, repairing leakage or sterilization. These tasks will be hard to perform under high temperature.
Extreme temperature occurrences (including heat waves)	Likely	Likely	Same as above.
Extreme rainfall change	N/A	N/A	It is expected that will be no change in the increasing of the intensity of precipitation in the project area.
Water availability	Rare	Rare	Although the rainfall is expected to decrease, it will not result in a reduction in water reserves.
Flooding	Likely	Almost certain	Although reduced rainfall will decrease the frequency of flooding in the country, the project area belongs to a flooding zone and the exposure of the project characterized as high (Baseline and future) according to UNWFP (2019) study (Figure *8* refers).
Seawater temperature	N/A	N/A	Discharged brine will not increase the seawater temperature.

[5] The number between parenthesis refers to the climate hazard that might affect the project as listed in Table 4.

Climate variables and hazards	Probability ranking for Marine Works	Probability ranking for Desalination Plant	Explanation
Relative sea level rise	Likely	Likely	Sea level rise is expected to occur at the Gulf of Aqaba, which will bring several consequences including coastal retreat leading to land area loss in the already small area of the Gulf of Aqaba.
Storm surges	Rare	Rare	Outlet failure during storm surges might lead to brine discharge into the Gulf of Aqaba.
Saline intrusion	N/A	N/A	Should saline water reach the inlet pump station and the desalination plant infrastructure, it will not cause any damage to equipment since it is designed to withstand that exposure.
Ocean salinity	Likely	Likely	Changes in the concentrations of salt in seawater is projected to increase as a result of brine disposal affecting aquatic flora and fauna.
Ocean pH	Likely	Likely	The rapid increase of atmospheric CO2 has caused oceans and seas to absorb increasingly greater amounts of CO2. This process disturbs the pre-existing chemical equilibrium of the sea, resulting in seas changing their chemical state and altering the ocean pH. By 2100, under medium emissions scenarios, ocean pH is projected to decrease by 0.3 pH units from levels 100 years ago. Hence this parameter has minor effect in the present and future climate.
Coastal erosion	Likely	Likely	Increased sea level rise can lead to coastal erosion.
Soil erosion	N/A	Likely	Increased temperature, prolonged droughts lead to desertification and soil erosion.
Average wind speed	Possible	N/A	The design of brine outlets was based on 'still' conditions which is the worst-case scenario in terms of achieved dilutions. Currents will further enhance brine dilution. Submerged structures may be affected in the presence of strong currents unless properly moored.
Maximum wind speed	Possible	N/A	Same as above.
Droughts	N/A	N/A	Frequent and intense periods of drought will not impact the ability to meet the needs of water users and provide essential municipal operations and services.
Air quality	Rare	Likely	Seawater lift pumps and equipment in the desalination plant create an airborne noise source that impacts upon neighborhood amenity.
Cold spells	N/A	Rare	The buildings and facilities most vulnerable to extreme winter storms include those with priorities for clearing snow and re-establishing access, those that may experience compromised building integrity from additional snow load, and those that have building functions and equipment that could be impacted by corresponding cold temperatures.

Table 27: Justification for Probability Ranking for Pipeline and Reservoirs and Pumping Stations

Climate variables and hazards	Probability ranking for Pipeline	Probability ranking for Reservoirs and Pumping Stations	Explanation
Average air temperature increase	Almost certain	Almost certain	Pipeline and pumping stations contain a lot of confined spaces. Workers must enter those confined spaces to carry out some tasks such as removing fouling, repairing leakage or sterilization. These tasks will be hard to perform under high temperature.
Extreme temperature occurrences (including heat waves)	Likely	Likely	Same as above.
Extreme rainfall change	N/A	N/A	It is expected that will be no change in the increasing of the intensity of precipitation in the project area.
Water availability	Likely	Rare	More frequent precipitation events paired with the inability to store the increased volumes of water puts the community at-risk for water availability issues.
Flooding	Almost certain	Likely	Although reduced rainfall will decrease the frequency of flooding in the country, the project area belongs to a flooding zone and the exposure of the project characterized as high (Baseline and future) according to UNWFP (2019) study (Figure 8).
Seawater temperature	N/A	N/A	The seawater temperature will not affect these 2 components.
Relative sea level rise	Rare	N/A	Relative sea level rise at entry points in the transmission system, such as the air release blow-off valves.
Storm surges	Rare	Rare	Flooding at the pumping stations and entry points in the transmission system, such as the air release blow-off valves, will defect the equipment.
Saline intrusion	N/A	Rare	Should saline water reach the pumping station infrastructure, it will cause serious damage to equipment not designed to withstand that exposure. From a system point of view these expected effects will cause reduced operational efficiency and might lead to design failure.
Ocean salinity	N/A	N/A	Ocean salinity will not affect these 2 components of the project.
Ocean pH	N/A	N/A	Ocean pH will not affect these 2 components of the project.
Coastal erosion	Rare	N/A	Coastal erosion can lead to damage of transmission pipeline system.
Soil erosion	Rare	Rare	Increased temperature, prolonged droughts lead to desertification and soil erosion.
Average wind speed	N/A	N/A	The average wind speed or the direction of winds in the area are not expected to change significantly in the present or in the future.
Maximum wind speed	N/A	N/A	According to future projections no significant change in maximum wind speed is expected.
Droughts	N/A	N/A	Droughts will not affect these 2 components of the project.

Climate variables and hazards	Probability ranking for Pipeline	Probability ranking for Reservoirs and Pumping Stations	Explanation
Air quality	N/A	Likely	Pumps create airborne noise source that impacts upon neighbourhood amenity
Cold spells	Rare	Rare	Pipeline, and the buildings and facilities most vulnerable to extreme winter storms include those with priorities for clearing snow and re-establishing access, those that may experience compromised building integrity from additional snow load, and those that have building functions and equipment that could be impacted by corresponding cold temperatures.

3.4.2. Severity (Impact analysis)

This part of the risk assessment looks at what would happen if the identified climate hazard did occur, what would be the consequences. This will be assessed on a scale of severity per hazard and can also referred as magnitude.

The scale which used for the specific analysis are a scale of 5 levels (insignificant, minor, moderate, major, catastrophic). Table *28* presents the scale for assessing the severity (impact analysis) of each climate hazard.

Table 28: Scale for Assessing the severity of Consequence

1	2	3	4	5
Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
Minimal impact that can be mitigated through normal activity.	An event which effects the normal project operation, resulting in localised impacts of a temporary nature.	A serious event requiring additional actions to manage, resulting in moderate impacts.	A critical event requiring extraordinary action, resulting in significant, widespread or long-term impacts.	Disaster with the potential to lead to shut down or collapse of the asset / network, causing significant harm and widespread long-term impacts.

For the implementation of the Risk Assessment Matrix for the four components of the project the essential climate related hazards which should be further examined regards severity, are the same with them that examined regarding probability. The following will be examined:

- For the component of Marine works the following are examined: Average air temperature increase (1), Extreme temperature occurrences (including heat waves) (2), Extreme rainfall events (4), Water availability (5), Flooding (coastal and fluvial) (7), Seawater temperature (8), Storm surges (10), Saline intrusion (11), Ocean salinity (12), Ocean pH (13), Coastal erosion (14), Droughts (22), Air quality (25).
- For the component of Desalination plant the following are examined: Average air temperature increase (1), Extreme temperature occurrences (including heat waves) (2), Extreme rainfall events (4), Water availability (5), Flooding (coastal and fluvial) (7), Storm surges (10), Saline intrusion (11), Ocean pH (13), Coastal erosion (14), Soil erosion (15), Droughts (22), Air quality (25).
- For the component of Pipeline the following are examined: Average air temperature increase (1), Extreme temperature occurrences (including heat waves) (2), Extreme rainfall events (4), Water Availability (5), Flooding (coastal and fluvial) (7), Storm surges (10), Saline intrusion (11), Coastal erosion (14), Soil erosion (15), Droughts (22), Air quality (25).
- For the component of Reservoirs and pumping stations the following are examined: Average air temperature increase (1), Extreme temperature occurrences (including heat waves) (2), Extreme

rainfall change (4), Water Availability (5), Flooding (coastal and fluvial) (7), Storm surges (10), Saline intrusion (11), Coastal erosion (14), Soil erosion (15), Droughts (22), Air quality (25).

The severity of each one of the climate related hazards for each component are presented in Table 29.

Table 29: Severity Ranking for the Components of the Project

		Climate Related Hazards[6]																		
Project type	**Severity**	Average air temperature increase (1)	Extreme temperature occurrences (including heat waves) (2)	Extreme rainfall events (4)	Water availability (5)	Flooding (coastal and fluvial) (7)	Seawater temperature (8)	Relative sea level rise (9)	Storm surges (10)	Saline intrusion (11)	Ocean salinity (12)	Ocean pH (13)	Coastal erosion (14)	Soil erosion (15)	Average wind speed (18)	Maximum wind speed (19)	Droughts (22)	Air quality (25)	Cold spells (29)
AAWDCP	Marine works																			
	Desalination plant																			
	Pipeline																			
	Pump stations and reservoirs																			

Justification for the severity ranking per climate related hazard is presented in Table *30* and Table *31*.

Table 30: Justification for Severity Ranking for Marine Works and Desalination Plant

Climate variables and hazards	Severity ranking for Marine Works	Explanation	Severity ranking for Desalination Plant	Explanation
Average air temperature increase	Insignificant	The average air temperature increase does not significantly affect water temperature beyond values that are detrimental to the marine works function.	Insignificant	The average air temperature increase does not significantly affect water temperature beyond values that are detrimental to the desalination plant activities.

[6] The number between parenthesis refers to the climate hazard that might affect the project as listed in Table 4.

Climate variables and hazards	Severity ranking for Marine Works	Explanation	Severity ranking for Desalination Plant	Explanation
Extreme temperature occurrences (including heat waves)	Insignificant	The extreme air temperature occurrences do not significantly affect water temperature beyond values that are detrimental to the marine works function.	Minor	The placement of the desalination plant units in an open space which is not protected against the influence of the increase in temperature makes this plant more sensitive to this climate hazard.
Extreme rainfall change	N/A	Extreme rainfall change will not impact this component.	N/A	Extreme rainfall change will not impact this component.
Water availability	N/A	Water availability will not affect the process.	N/A	No impact can occurr in the desalination plant process due to less quantities of available water.
Flooding	Insignificant	Flooding will not significantly affect submerged structures beyound values that are detrimental to the marine works function.	Major	Due to the fact that the project area belongs to a flooding area and considering the decreased rainfalls according future projections, the impact can characterized as major.
Seawater temperature	N/A	Discharged brine will not increase the seawater temperature.	N/A	Discharged brine will not increase the seawater temperature.
Relative sea level rise	Insignificant	Potential runoff of seawater will affect the intake pumping station but the severity response is considered to be insignificant.	N/A	Potential runoff of seawater will not affect the desalination plant since the plant site is at +100 m amsl.
Storm surges	N/A	Storm surges will not affect the marine works.	Moderate	Storm intensities and frequencies will change as a result of climate change causing increased water levels storm damage, risk of flooding from surrounding wadis and defence failure.
Saline intrusion	N/A	Should saline water reach the inlet pump station, it will not cause any damage to equipment since it is designed to withstand that exposure.	N/A	Should saline water reach the desalination plant infrastructure, it will not cause any damage to equipment since it is designed to withstand that exposure.
Ocean salinity	Moderate	Changes in the concentrations of salt in seawater is projected to increase as a result of brine disposal affecting aquatic flora and fauna.	Moderate	Changes in the concentrations of salt in seawater is projected to increase as a result of brine disposal affecting aquatic flora and fauna.
Ocean pH	Moderate	Changes in the pH of salt in seawater is projected to change as a result of brine disposal affecting aquatic flora and fauna.	Moderate	Changes in the pH of salt in seawater is projected to change as a result of brine disposal affecting aquatic flora and fauna.
Coastal erosion	Insignificant	Coastal erosion on depends on sea level rise. See above.	Insignificant	Coastal erosion on depends on sea level rise. See above.

Climate variables and hazards	Severity ranking for Marine Works	Explanation	Severity ranking for Desalination Plant	Explanation
Soil erosion	N/A	Soil erosion will not impact this component.	Insignificant	Potential localized contamination of soils or groundwater/surface water systems and potential adverse impacts on flora and fauna
Average wind speed	Insignificant	Average wind speed can affect the process but the severity response considered to be insignificant.	N/A	Average wind speed will not impact this component.
Maximum wind speed	Insignificant	Maximum wind speed can affect the process but the severity response considered to be insignificant.	N/A	Maximum wind speed will not impact this component.
Droughts	N/A	Droughts will not impact this component.	Moderate	Frequent and intense periods of drought will impact the ability to accommodate growth, meet the needs of water users, and provide essential municipal operations and services.
Air quality	Insignificant	Air quality can affect the process but the severity response considered to be insignificant.	Moderate	Potential excessive greenhouse gas production
Cold spells	N/A	Cold spells will not impact this component.	Minor	Concrete structures reduce the impact of this climate hazard.

Table 31: Justification for Severity Ranking for Pipeline and Pump Stations and Reservoirs

Climate variables and hazards	Severity ranking for Pipeline	Explanation	Severity ranking for Pump Stations and Reservoirs	Explanation
Average air temperature increase	Insignificant	The underground placement of the water transmission pipeline leads to its protection against a gradual increase in the surface temperature.	Insignificant	The average air temperature increase does not significantly affect water temperature beyond values that are detrimental to the reservoirs and pumping stations.
Extreme temperature occurrences (including heat waves)	Insignificant	The underground placement of the water transmission pipeline leads to its protection against an extreme increase in the surface temperature.	Insignificant	The extreme air temperature occurrences do not significantly affect water temperature beyond values that are detrimental to the reservoirs and pumping stations.
Extreme rainfall change	N/A	Extreme rainfall change will not impact this component.	N/A	Extreme rainfall change will not impact this component.
Water availability	N/A	Water availability will not impact this component	N/A	Water availability will not impact this component

Climate variables and hazards	Severity ranking for Pipeline	Explanation	Severity ranking for Pump Stations and Reservoirs	Explanation
Flooding	Moderate	The underground placement of the water transmission pipeline leads to the moderate consequences as a result of flooding.	Moderate	Due to the fact that the project area belongs to a flooding area and considering the decreased rainfalls according to future projections, the impact can characterized as moderate.
Seawater temperature	N/A	The seawater temperature will not impact this component.	N/A	The seawater temperature will not impact this component.
Relative sea level rise	N/A	The relative sea level rise will not impact this component	N/A	The relative sea level rise will not impact this component
Storm surges	Insignificant	Storm surges may occur at entry points of transmission pipeline such as the air release blow-off valves	Insignificant	Storm surges might reach the pumping station infrastructure and cause damage to equipment if not designed to withstand that exposure. From a system point of view these expected effects will cause reduced operational efficiency.
Saline intrusion	N/A	Saline intrusion will not impact this component.	N/A	Saline intrusion will not impact this component.
Ocean salinity	N/A	Ocean salinity will not impact this component.	N/A	Ocean salinity will not impact this component.
Ocean pH	N/A	Ocean pH will not impact this component.	N/A	Ocean pH will not impact this component.
Coastal erosion	N/A	Coastal erosion will not impact this component.	N/A	Coastal erosion will not impact this component.
Soil erosion	Insignificant	The underground placement of the water transmission pipeline leads to the absence of negative consequences as a result of soil erosion.	Insignificant	Potential localized contamination of soils or groundwater/surface water systems and potential adverse impacts on flora and fauna
Average wind speed	N/A	Average wind speed will not impact this component	N/A	Average wind speed will not impact this component
Maximum wind speed	N/A	Maximum wind speed will not impact this component	N/A	Maximum wind speed will not impact this component
Droughts	N/A	Droughts will not impact this component	N/A	Droughts will not impact this component
Air quality	N/A	Air quality will not impact this component	Moderate	Potential excessive greenhouse gas production
Cold spells	Insignificant	The underground placement of the water transmission pipeline leads to the absence of negative consequences as a result of cold spells.	Minor	Concrete structures reduce the impact of this climate hazard.

3.4.3. Risk assessment

Having assessed the severity and probability of each hazard occurring, the significance level of each potential risk can be determined through a combination of the two factors. Table *32* presents the template which has been followed in order to prepare the risk matrix considering the probability and severity ranking presented in previous sections.

Table 32 :Risk Matrix

	Probability	Rare	Unlikely	Possible	Likely	Almost Certain
Severity		1	2	3	4	5
Insignificant	1	1	2	3	4	5
Minor	2	2	4	6	8	10
Moderate	3	3	6	8	12	15
Major	4	4	8	12	16	20
Catastrophic	5	5	10	15	20	25

Negligible Risk
Low Risk
Medium Risk
High Risk
Extreme Risk

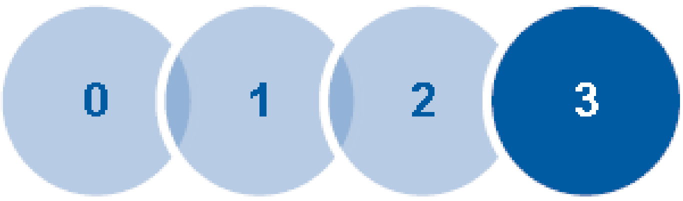
Table *33* presents the risk assessment analysis by combining the probability (likelihood) and severity (impact) of each climate related hazard for the four components of the project.

Table 33 :Risk Matrix Based on Indicators of Probability and Severity of Detected Climate Related Hazards

Project type	Project Component	Climate Related Hazards[7]																	
		Average air temperature increase (1)	Extreme temperature occurrences (including heat waves) (2)	Extreme rainfall events (4)	Water availability (5)	Flooding (coastal and fluvial) (7)	Seawater temperature (8)	Relative sea level rise (9)	Storm surges (10)	Saline intrusion (11)	Ocean salinity (12)	Ocean pH (13)	Coastal erosion (14)	Soil erosion (15)	Average wind speed (18)	Maximum wind speed (19)	Droughts (22)	Air quality (25)	Cold spells (29)
AAWDCP	Marine works	5	4		1	4		4	1		12	12	4		3	3		1	
	Desalination plant	5	8		1	20		4	3		12	12	4	4			3	12	2
	Pipeline	5	4		4	12		1	1					1					1
	Pump stations and reservoirs	5	4		1	12			1	1				1				12	2

3.5. Task 3-Adaptation

If the risk assessment concludes that there are significant risks to the project from climate change, these risks need to be managed and reduced to an acceptable level. For each significant risk identified, various adaptation measures should be proposed and assessed.



The preceding analysis identified that the potential climate hazards with high level of risk which can affect the marine works are ocean salinity and pH.

Regarding the desalination plant, the potential climate hazard with medium level of risk which can affect it is extreme temperature occurrences (including heat waves). As for potential climate hazards with high level of risk, ocean salinity and pH, and air quality were identified. Flooding was identified as the extreme high risk climate hazard that might affect the desalination plant.

On the other hand, the risk assessment revealed that there flooding is the only potential climate hazard with high level of risk which can affect the pipeline component of the project.

As for the pump stations and reservoirs, flooding and air quality are identified as a potential climate hazards with high level of risk that need adaptation measures.

[7] The number between parenthesis refers to the climate hazard that might affect the project as listed in Table 4.

In general, adaptation options often involve a mix of structural and non-structural options. The former includes modifications to the design or specification of physical assets and infrastructure, or the adoption of alternative or improved solutions. The latter includes improved monitoring or emergency response programmes, staff training and skills transfer activities, development of strategic or corporate climate risk assessment frameworks, financial solutions such as insurance against supply chain failure or alternative services.

High temperatures were identified as a risk to the desalination plant operations due to the potential impact on plant personnel, and it is recommended that the plant managers consider developing a policy to manage this risk. The policy should consider measures to manage the risk to workers, such as:

- Stopping work or working in shifts during very high temperatures
- Ensuring personnel have appropriate personal protective equipment such as hats, long-sleeved shirts, sunglasses and sunscreens.
- Providing air-conditioned areas for workers seek respite from the heat if required; and
- Ensuring personnel are provided with access to potable water.

Effective adaptation strategies against flood risks are needed for the desalination plant, pipelines and pump stations and reservoirs, which combine flood protection infrastructure, nature-based solutions, and risk financing schemes to manage floods and buffer their economic impacts (Jongman, 2018). Effective adaptation to rising flood risk requires a diversified approach of interventions, which may include structural flood protection measures, early warning systems, risk-informed land planning, nature-based solutions, social protection, and risk financing instruments (Aerts et al., 2014).

Physical flood protection measures, such as dikes and levees, are generally cost-effective in areas with high population and asset concentrations (Ward et al., 2014). However, such protection works require immense capital investments for construction and maintenance, for which both political momentum and government budgets are often missing. In addition, research in the field of socio-hydrology has shown that increasing flood protection can give a false sense of security and may boost development in these protected flood-prone areas. However, while the resulting system may have a lower risk overall, the potential impacts of a dike-breaching event can be catastrophic (Ciullo et al., 2017).

Recently, governments are increasingly turning to nature to manage flooding (Temmerman et al., 2013). Such nature-based solutions include widening of natural flood plains, protecting and expanding wetlands, and investing in urban green spaces to reduce run-off. In addition to effectively reducing flood risk, nature-based solutions can have a wide range of positive effects on ecosystem conservation, carbon storage, tourism and local employment. Implementing natural approaches often also requires the involvement of various stakeholder groups, thereby helping with awareness raising and consensus building.

The Jordanian coast of the Gulf of Aqaba is characterized by rocky coral reef structures interspaced by valleys running down from the surrounding mountains. These valleys are dry most of the year but experience a couple of flash floods per year. ASEZA has established a system of dams to harvest rainwater and to reduce floods impact on the coastal developments and habitats.

As stated before, the proposed AAWDC pipeline will cross the main Wadi Yutum Interchange and will pass along its Wadi bank for approximately 5km. Despite the reduction in peak flow rates that the flood attenuation dams might achieve, the flood risk for the purpose of this study is still considered high, thus necessitates a carefully design and robust construction, including scour studies and scour protection measures, including but not limited to: construction below scour depth, encasement, scour protection, etc.

Intake suction heads are designed to minimize entrainment and impingement effects - In order to minimize entrainment and impingement of biota from the intake of seawater, the design of the intake suction heads assures a slow suction velocity of 0.15 m/sec, comparable to normal ambient sea currents. Such velocity is slow enough to allow virtually all mobile organisms (e.g. fish, large crustaceans) to swim away from the intake and avoid impingement, as well as to minimize the potential for entrainment of drifting small biota (plankton, fish eggs, larvae). Therefore, significant ecological losses to source populations of the entrained/impinged species are not expected.

Salinity and pH, because of the brine discharge of the marine works and desalination plant, can play a considerable role in determining the abundance and distribution of flora and fauna's species. For the AAWDCP, brine dispersion modelling has been carried out, which demonstrates that a well-designed outfall diffuser system can achieve brine dispersion to a salinity of 1.3-2% above the ambient at 100m from the diffusers. It is anticipated that a dispersion of less than 2% should provide protection for the local flora and fauna outside of the mixing zone. The Environmental and Social Impact Assessment (ESIA) team recommends that long term Whole Effluent Toxicity testing is carried out by the Project developer during plant construction and early plant operation as a monitoring tool to confirm the actual brine toxic effects to selected and examined local species at the area of discharge (i.e., protective dilution to have no observable impact on the flora and fauna outside of the 100m mixing zone).

Seawater reverse osmosis (SWRO) results in a cleaner and an environmentally far less disruptive brine discharge than the brine generated by thermal desalination plants, as there is no large temperature increase of brine (only 0.5 to 1 deg. C), no discharge of heavy metals like copper from heat exchanger tubes, no antifoams and less antiscalants (no calcium sulphate scale potential). The brine from SWRO plants themselves have also become cleaner over the past 20 years because of the increased experience in operating large SWRO facilities using polyamide spiral wound membranes. The average iron coagulant dosages used are lower at 0.5mg/l - 1mg/l, acid dosing and polymer aids for coagulation are now rarely used, and real RO membrane antiscalant doses used are lower than antiscalant software predictions.

The ESIA team considers a precautionary view is appropriate relative to the type of wastes being generated by the SWRO that could be allowed to be discharged to the sea. The desalination facility must also be operable and maintain plant availability. The precautionary principle is manifested by key Project recommendations that include:

a) The high salinity reject brine should be dispersed very rapidly in the ambient seawater in a small mixing zone. The salinity at a distance of 100m from the diffusers should be less than or equal to 2% (approximately 0.8ppt) above the ambient. This is achieved by designing the outfall diffusers with Froude number ≥ 20. However, the long term effects of continuous brine discharge to water stratification cannot be determined without long term dedicated modelling.
b) Setting an end-of-pipe standard for DO 3.5mg/l and through to dilution achieved by diffusers the brine DO will return very quickly to ambient levels at short distance from the diffusers (less than 100m).
c) The brine should be chemically clean as practical. Chemicals or ions, that do not already exist in the abstracted ambient seawater, should not be discharged to the Gulf of Aqaba unless there is no practical alternative for an operable SWRO facility.
d) Brine will be discharged at a water depth of about 50m (at least deeper than 35m based on modelling) at a slope and about 40m deeper than the intake. Therefore, exposure to saline intrusion through brine recirculation is unlikely at the intake towers. This was verified by far field modeling conducted by the ESIA team.
e) No RO membrane spent cleaning chemicals that are organic, biocides, or phosphorus/nitrogen nutrient sources should be discharged with the brine. Should such chemicals be used in the project, these should be either treated on-site or off-site. Salts of simple acids and bases used in membrane cleaning can be allowed to be discharged with the brine after neutralization.
f) Solids removed by the seawater pre-treatment, post treatment, and membrane cleaning in place (CIPs) should be treated at a solid removal facility with sludge thickening and dewatering facility for off-site disposal as a sludge cake. Cleared supernatant meeting set turbidity targets can then be mixed with the brine for outfall disposal.
g) Appropriate end of pipe discharge limits for Iron, Chlorine Residual (zero), Turbidity, Dissolved Oxygen, and pH have been recommended by the ESIA team to feed into process design considerations.

During the construction of the intake and outfalls, enhanced protection of marine environment is envisaged including the following key measures:

- Minimize the excavation of the seabed to that required to ensure intake pipe and outfall pipe stability (i.e., minimum trench for gravel bed).
- Fully bury the intake and outfall pipes only in the surf zone.
- Use of silt curtains to minimize the turbidity impact of dredging.
- Relocation of corals that are located in the path of the intake and outfall pipelines where this is safe for divers to do so.

Regarding air quality, one way to reduce the carbon footprint of seawater desalination is to utilize renewable sources, such as solar or wind power, to generate electricity needed to operate the plant. Requiring new seawater desalination plants to only use renewable sources of energy would reduce indirect GHG emissions related to the large energy demand of the desalination plants. If this requirement increased demand for renewable energy, it could also serve as an incentive to invest in more renewable energy production.

Other adaptation techniques that can be adopted after start of operations are:

Terrestrial:

- Minimal energy consumption (power plant fueled by natural gas or renewable energy).
- Acoustic insulation and minimal external lighting.
- Minimal use of process chemicals – safety measures for transportation, storage and handling, containers for solid waste and authorized landfill disposal.
- Pipelines laid underground.

Marine:

- The use of submerged intake towers for the abstraction of seawater is by far the most common and proven solution for SWROs. For the AAWDC project, the use of three intake towers is envisaged. The tower though screen velocity is recommended to be <= 0.15m/s (slow suction velocity to prevent impingement) with all three intake towers in operation at ultimate capacity.
- The intake tower window will be >=3m above the seabed to reduce sand/silt entrainment from the seabed. The intake window will be >=5m below the seawater level to reduce potential entrainment of floating pollution, particularly hydrocarbons. Additional mitigation relative to protection from hydrocarbons spillages would be to install an oil detection and alarm system at IPS; the plant should subsequently shut-down when the set alarm level is reached, and install a floating barrier around the intake towers.
- For macrofouling control of the marine intake pipes, the use of mechanical pigging with mandrel pigs using polyurethane rings has been proven to work very effectively for the SWRO projects at Hadera and Ashkelon in Israel. This method does not require the use of chlorination, and therefore does not generate any trihalomethanes (THMs) to be discharged to the Gulf of Aqaba.
- Self-cleaning traveling screen for debris collection at the intake system and disposal in authorized waste disposal sites.
- Outfall diffuser system with high velocity jet diffusers to increase initial dilution and reduce brine salinity to ambient levels.
- Reduction of brine discharge by considering 2 recovery scenarios (42% and 45%).
- Reduction of use of chemicals in the process.
- Land based treatment of backwash effluents (pre-treatment, post-treatment, and CIPs) for solids removal before mixing with the brine for outfall disposal.
- Use of environmentally friendly chemicals (e.g. nitrogen and phosphorus free antiscalants, if antiscalants are to be used based on pilot testing).

Environmental monitoring is essential and, therefore, for the establishment of baseline conditions before and after construction commencement, as well as operational monitoring developers of AAWDCP should:

- Undertake their own bathymetry survey.
- Conduct water column vertical profiling through conductivity (salinity) – temperature – depth (CTD) at proposed diffuser location and 100m from the diffusers and at ambient control location.
- Undertake marine species survey through underwater video recording and species identification / mapping repeated monthly during project design and then repeated once after construction completion to establish the “new” baseline conditions in the near field path of the brine plume.
- Conduct water quality sampling survey with focus on salinity, temperature, and nutrients (NH_3 and phosphates near sources where pollution is suspected).
- Conduct continuous monitoring of turbidity, temperature, pH, dissolved oxygen (DO), and conductivity/salinity during design and construction phases, by setting up a monitoring buoy (at proposed intake location).

Moreover, adaptation measures at Ministerial (MWI) level should include training, awareness raising, and capacity building relative to climate change:

- Encourage public awareness and behavioral change by working with existing networks.
- Build political will to address climate change in water management.
- Raise public awareness about water saving, water-related issues, and water management. Train experts in the water sector to write successful proposals to access international climate funds.

Within the next 20 years, it is estimated that the MENA region will become so dependent on desalination technology for sustainable water supply that a minimum of 50,000 additional technical experts of various professional levels will be needed to service the desalination industry (Ghaffour, 2009).

The initiation, formulation and implementation of desalination plants need organizational structures for managing required activities at the governmental level as well as within the utilities, industry, research and development, and educational institutes involved. The distribution of tasks, functions and responsibilities among involved organizations is required. The function of these organizations will be to ensure their design, manufacture, construction, commissioning and operation of desalination plants.

Any country considering a desalination program should have a national energy and water policy specifying the objectives for the national energy and water plans (Al-Mutaz, 2001). Key aspects to be addressed by the national energy and water policy should include:

- Improved energy independence.
- Development of indigenous energy and water resources and their infrastructure and distribution.
- Optimum management of energy and water supply.
- Stable and secure energy and water supply.
- Energy and water demand projections.
- Pricing of energy and water.

The analysis of the water structure should include the following aspects:

- Water consumption by different sectors.
- Water production, availability, and source potential.
- Cost structure of the fresh water produced or treated and supplied.

The objective of such an analysis is to determine the trends in the composition of consumption of water, water sources and costs. In order to develop a national water policy, a survey is needed to provide a reasonable knowledge of the country's available and potential water resources. The survey should consider fulfilment of national water requirements from natural resources and water reclamation.

In 2016, Jordan has developed its National Water Strategy 2016-2025 in a national cross-sectoral document, as it is focused on building a resilient sector based on a unified approach for a comprehensive social, economic and environmentally water sector development (MWI, 2016). Basic objective of this National Water Strategy is the sustainable management of water and sanitation for all Jordanians. To achieve the goal, the strategy essentially covers the national water sector goals and approach through the five following key areas:

(i) integrated Water Resources Management;
(ii) water, sewage and sanitation services;
(iii) water for irrigation, energy and other uses;
(iv) institutional reform; and
(v) sector information management and monitoring.

The strategy also, in the last chapter, rapidly addresses cross-cutting issues of climate change adaptation; trans-boundary/shared water resources; humanitarian water, sanitation, and hygiene sector coordination; public/private partnerships; and the economic dimensions of water. The National Water Strategy also emphasizes increased use of nonconventional water sources such as treated wastewater and desalinated seawater to bridge the shortfall in supply. Projects such as the As Samara Wastewater Treatment Expansion and the Red Sea to Dead Sea Conveyor are important components of this strategy (Van den Berg et al., 2019).

Capacity-building is urgently needed at different levels: operators, educators, academics and management. Achieving this target requires specific training efforts in desalination technologies to encompass the principles, practice, operation and maintenance, design, human resources management as well as research and development. Such a capacity-building program is necessary not only to operate and improve the new desalination plant but also to develop new sustainable technologies.

The training must be conducted by highly qualified professional instructors and must include the following activities:

- Classroom instructions in the theoretical aspects of the technologies and practical training in water processing.
- Adjusting parameters such as: produced water quality, quantity, and feed water salinity in order to simulate any scenario that might occur during the operation of SWRO.
- Actual processing under real operating conditions using processing equipment installed at AAWDCP.
- Ability to create problems such as chemical attack, scaling and fouling for troubleshooting techniques.
- Cement learning by including extra instrumentation and sampling points at every stage of the water treatment process.
- Formal examination to test trainees' proficiency.
- Award certificates upon successful completion course.

Prior to the opening of the first desalination plant in Aqaba in 2017, IHE Delft Institute for Water Education delivered a 4-day intensive course on the design, operation and maintenance of SWRO systems for 25 engineers and scientists from various organisations (Water Authority of Jordan (WAJ), Jordan valley Authority, Kemapco, Aqaba Water, Jordan University, AquaTreat) at the Jordan University Marine Science Station in Aqaba (UN-IHE, 2017).

This initial course and additional scheduled training were part of the SCARCE project funded under the Dutch 'Global Partnership for Water and Development'. The SCARCE project (Desalination, Diplomacy & Water Reuse in the Middle East) also provided equipment and specialized instruction for staff of the Marine Science Station and the WAJ so they can perform water quality tests required to monitor and operate membrane-based desalination systems. A database of seawater quality will be also created to help ensure smooth SWRO plant operation with information on areas including the Silt Density Index, Modified Fouling Index, Adenosine Triphosphate, Assimilable Organic Carbon and Transparent Exopolymer Particles measurements in seawater (UN-IHE, 2017). The learning outcomes from this training can be used in the AAWDCP in additional to more training sessions designed specifically for this project.

Overall, by assuming robust design standards are followed, the structural and electrical & mechanical features of the AAWDC Project are expected to provide a high degree of resilience to climate risks and relative risk ranking is expected to be reduced. Increases in both the magnitude and frequency of climate extremes, as described in previous sections, will continue to present a risk to structures, surfaces, and equipment. This is, however, primarily expected to result in an increased requirement for response to hazards as well as repair and maintenance of assets and systems. Climate change will also affect the operational environment of the RO desalination plant and the pumping stations; these facilities will need to provide sufficient cooling (air conditioning) systems to provide a suitable working environment.

Considering that the AAWDC Project is to be procured as a BOT scheme, it is noted that typically these adaptation measures are part of the detailed engineering design and construction cost estimating process or the usual operation and maintenance routine of desalination and water conveyance infrastructure. Therefore, such measures will be itemized and costed at the later stage of detailed design as constituent elements of the investment CAPEX and ensuing OMEX of the primary project components.

Conclusively, climate resilience of the primary project components can be improved through:

- **Environmental impact mitigation** – Identify measures to reduce the impact of the Project on the wider environment that is expected to be further compounded by climate change (i.e., using energy efficient equipment).

- **Climate change projections** - Given the level of uncertainty in future climate change projections, factoring in climate change projections into designs is also important. Moreover, while it is assumed that the financial and economic viability of the Project has incorporated climate change adaptation measures, costs and benefits of any additional adaptation measures should be explored at the detailed design stage of the primary project components.

- **Resilient construction** – Construction sites are likely to be vulnerable to current and future climate variability and extremes, as noted in this Report. In addition, climate variability and extremes can exacerbate construction impacts on the wider environment. Following appropriate construction Codes of Practice and adhering to a Construction Environmental Management Plan (CEMP) will help to reduce the risk of significant impacts. The promotion, and implementation, of an Emergency Response Plan (ERP) will also serve to reduce risks to assets and people.
- **Review design standards and selection of materials** – The assessment presented in this Report has been undertaken on the assumption that existing design standards are robust to climate risks, particularly to extremes. The selection of appropriate materials and design should consider the risk presented by climate change and how this may change over the design life of the primary project components, in addition to the cost, feasibility, and contribution to the outcomes of the adaptation measures. This should not be limited by design standards as these may, unintentionally, make the primary project components vulnerable in the long-term.
- **Resilient asset management/maintenance** – Practices for the operation and maintenance of assets associated with the primary project components should be reviewed by the project developer to take account of climate risks and changes in these risks over time. Maintenance of structures and surfaces will provide a degree of resilience to climate risks. These activities also provide the opportunity to assess vulnerability and impacts and make improvements as part of maintenance, modification, or replacement regimes. Retrofitting of measures to reduce vulnerability can be undertaken during asset management/maintenance activities.
- **Wider sustainability measures** – Implementing initiatives in support of wider sustainability that also improve the Project's climate resilience. For example, the use of renewable energy sources. This will reduce the Project interdependency on wider power infrastructure, providing a high degree of resilience to regional climate impacts that may affect the region's energy infrastructure.
- **Monitoring and evaluation** - Given the level of uncertainty in future climate change projections, it is important to ensure that resilience/adaptation measures are monitored and that evaluation is carried out by the project developer. In the first instance, this can support improvement of existing measures but also may help to ensure that lessons can be taken from the measures for incorporation into future projects.

4. References

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