UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Strengthen the National Multi-Hazard Early Warning System in the Sultanate of Oman

Annex 2: Feasibility Study

Executive Summary

The National Multi-Hazard Early Warning System project is a crucial initiative aimed at enhancing Oman's capacity to predict, monitor, and respond to various natural hazards, including tropical cyclones, floods, and extreme weather events. The project seeks to strengthen the nation's resilience to climate change impacts, protecting lives, infrastructure, and economic stability.

Chapter 1: Context Setting

Oman's geographic and climatic conditions make it particularly vulnerable to natural disasters. The country has a long coastline exposed to tropical cyclones and interior regions susceptible to flash floods. Recent years have seen an increase in the frequency and severity of these events, driven by climate change. This has highlighted the urgent need for a comprehensive and advanced early warning system to protect the population and critical infrastructure.

The NMHEWS project is designed as part of Oman's broader climate adaptation strategy, aligned with the National Adaptation Plan. The project is supported by the Green Climate Fund and implemented by the United Nations Industrial Development Organization. It aims to provide Oman with a robust system for disaster risk reduction, ensuring that the country is better prepared to face future climate-related challenges.

Chapter 2: Feasibility Assessment

The feasibility assessment for the NMHEWS project examined the technical, financial, and institutional aspects of implementing a state-of-the-art early warning system in Oman. The assessment confirmed the viability of the project, given the current infrastructure, the capacity of national institutions, and the availability of international and domestic funding.

Key Findings from the Feasibility Assessment:

- **Technical Feasibility:** Oman has the foundational infrastructure required for the deployment of advanced meteorological and hydrological monitoring systems. However, significant upgrades are necessary to meet the demands of a modern multi-hazard early warning system.
- **Financial Feasibility:** The total budget for the NMHEWS project is estimated at $35 million USD. The project will be funded by a combination of $22 million USD from the Green Climate Fund and $13 million USD from the Government of Oman. This financial arrangement ensures that the project has the necessary resources for successful implementation.
- **Institutional Feasibility:** Oman's Directorate General of Meteorology and other relevant national authorities have the capacity to manage and operate the NMHEWS. However, additional training and capacity building are required to fully leverage the advanced technologies that will be deployed.

The feasibility assessment also emphasized the importance of engaging with key stakeholders, including government ministries, private sector partners, and international organizations, to ensure the successful implementation and sustainability of the NMHEWS project.

Chapter 3: Detailed Project Information

This chapter provides a comprehensive overview of the NMHEWS project's scope, objectives, components, and the specific equipment to be deployed.

Project Scope and Objectives:

- **Project Scope:** The NMHEWS project encompasses the deployment of advanced meteorological equipment, the establishment of new monitoring stations, the enhancement of data processing and analysis capabilities, and the integration of these systems into a national early warning network.

- **Objectives:** The primary objective of the NMHEWS project is to improve Oman's ability to forecast and respond to natural disasters, thereby reducing the risk to human life, infrastructure, and the economy. The project also aims to build national capacities in disaster risk management and climate adaptation.

Overview of Equipment and Technology:

The NMHEWS project will deploy a wide range of state-of-the-art equipment and technologies to enhance Oman's early warning capabilities:

- **Geographic Information Systems (GIS):** ArcGIS Suite will enhance mapping, spatial analysis, and real-time data processing for hazard identification and scenario planning.
- **High-Performance Computing and Workstations:** Advanced computing systems and workstations will process large datasets, support complex simulations, and improve impact-based forecasting.
- **Drones for Data Collection:** A range of drones, including fixed-wing, multirotor, waterproof, thermal imaging-equipped, LiDAR-equipped, and long-endurance drones, will enable high-precision mapping, inspections, and post-disaster assessments.
- **Monitoring and Warning Systems:** X-band, C-band, and S-band radars, along with non-contact radar level gauges, will provide comprehensive weather monitoring and flood risk detection.
- **Communication and Dissemination Tools:** Emergency alert systems, mobile applications, mass notification software, SMS/email platforms, traditional broadcast tools will ensure timely dissemination of warnings and Data Analysis & Visualization with AI.
- **Disaster Preparedness and Response Equipment:** Drones with thermal cameras, training simulators, drill tools, mobile post-disaster evaluation units, emergency vehicles (ambulances), and centralized disaster dashboards will enhance preparedness, response, and recovery efforts.

Project Components:

The NMHEWS project is structured around three key components:

- **Component 1: Climate Information Services Delivery**: This component focuses on enhancing Oman's climate data collection and decision-making processes through strengthened policies, institutional capacity building, and modernized infrastructure.
- **Component 2: Impact-Based Multi-Hazard Early Warning Systems and Early Action**: This component aims to improve disaster risk knowledge, strengthen monitoring and forecasting capabilities, enhance communication systems, and build community and institutional preparedness for effective disaster response.
- **Component 3: Improving Climate Information and Early Warning Systems for Investment and Financial Decisions**: This component integrates climate information into decision-making processes to support climate-resilient infrastructure investments and financial planning, ensuring adaptive actions and sustainable resilience.

Chapter 4: Implementation Arrangements

The implementation of the NMHEWS project in Oman will be led by UNIDO as the Accredited Entity (AE) and the Environment Authority as the Primary Executing Entity (EE), supported by secondary implementing entities through Memorandums of Understanding (MoUs). The project governance and operational structure ensure clear roles, accountability, and collaboration to achieve the project objectives.

- **Project Implementation Structure**
  - **UNIDO** oversees project implementation, ensuring alignment with Green Climate Fund objectives. It is responsible for resource management, stakeholder coordination, risk assessment, and reporting.
  - **Environment Authority** leads on-the-ground implementation, supported by secondary implementing entities:
    - Directorate General of Meteorology: Responsible for climate information services delivery (Component 1).
    - National Center for Emergency Management and Civil Defence and Ambulance Authority: Jointly responsible for multi-hazard early warning systems and early action (Component 2).

- Ministry of Finance: Facilitates improvements in climate information systems for investment decisions (Component 3).

- **Governance and Operational Structure**
  - Project Steering Committee (PSC): Provides strategic oversight and decision-making, with representatives from UNIDO, the Environment Authority, and key national stakeholders.
  - Project Implementation Unit (PIU): Manages daily operations and coordination, ensuring smooth execution of activities.
  - Technical Working Groups (TWGs): Deliver technical outputs for each project component, addressing challenges and reporting progress to the PIU.
- **Capacity Assessment and Due Diligence Findings**
  - **UNIDO** has extensive experience in managing complex projects in Oman, including GCF-funded initiatives. It demonstrates robust financial systems, compliance with regulatory frameworks, and a proven track record in climate resilience and low-carbon development.
  - **Environment Authority** possesses the institutional capacity and technical expertise to implement the project. Capacity-building in advanced technology and data analysis is recommended to optimize its performance.
  - **Secondary Implementing Entities**: Government entities, such as the Directorate General of Meteorology, National Center for Emergency Management, Civil Defence and Ambulance Authority, and the Ministry of Finance, are well-positioned for their respective roles, with targeted capacity-building required for enhanced execution.

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List of Abbreviations

- **AE**: Accredited Entity
- **AFS**: Audited Financial Statements
- **AI**: Artificial Intelligence
- **APR**: Annual Performance Reports
- **BTR**: Biennial Transparency Report
- **Capex**: Capital Expenditures
- **CBA**: Cost-Benefit Analysis

- **CCKP**: Climate Change Knowledge Portal
- **CIEWS**: Climate Information and Early Warning Systems
- **CIS**: Climate Information Services
- **CMIPs**: Coupled Model Inter-comparison Projects
- **COP**: Conference of the Parties
- **CVI**: Coastal Vulnerability Index
- **DGM**: Directorate General of Meteorology
- **DJF**: December January February
- **EE**: Executing Entity
- **ECMWF**: European Centre for Medium-Range Weather Forecasts
- **EWS**: Early Warning System
- **FE**: Final Evaluation
- **GCF**: Green Climate Fund
- **GIS**: Geographic Information Systems
- **HPC**: High-Performance Computing
- **IMD**: India Meteorological Department
- **INDC**: Intended Nationally Determined Contributions
- **IPCC**: Intergovernmental Panel on Climate Change
- **IR**: Inception Report
- **IRMF**: Integrated Results Management Framework
- **IRR**: Internal Rate of Return
- **JTWC**: Joint Typhoon Warning Center
- **JAS**: July August September
- **MA**: March April
- **MJ**: May June
- **NAP**: National Adaptation Plan
- **NCCD**: National Committee for Civil Defence
- **NDCs**: Nationally Determined Contributions
- **NMHEWS**: National Multi-Hazard Early Warning System
- **NDA**: National Designated Authority
- **NDRR**: United Nations Office for Disaster Risk Reduction
- **NPV**: Net Present Value
- **O&M**: Operations and Maintenance
- **Opex**: Operational Expenditures
- **PIU**: Project Implementation Unit
- **PSC**: Project Steering Committee
- **RCPs**: Representative Concentration Pathways
- **SLR**: Sea Level Rise
- **SMS**: Short Message Service
- **SSPs**: Shared Socioeconomic Pathways
- **ToC**: Theory of Change
- **TWGs**: Technical Working Groups
- **UNDP**: United Nations Development Programme
- **UNDRR**: United Nations Office for Disaster Risk Reduction
- **UNFCCC**: United Nations Framework Convention on Climate Change
- **VTOL**: Vertical Take-Off and Landing
- **WMO**: World Meteorological Organization

Chapter 1: Context Setting

1. Climate of Oman

1.1. Temperature Pattern

The Sultanate of Oman is located in the South-East of the Arabian Peninsula along the latitude (16°40´ and 26°20´) North, and longitude (51°50´ and 59°40´) East. Oman, due to its geographical location astride the Tropic of Cancer, experiences an arid and dry climate. The region receives a substantial amount of shortwave solar radiation because the skies are mostly clear. This radiation is absorbed by the land and then re-emitted as longwave thermal radiation, heating the atmospheric boundary layer near the ground, which results in higher surface temperatures. Based on the reanalysis data from climate reanalysis produced by the ECMWF[1], this section analyzes the mean, maximum, and minimum surface temperatures in Oman from 1950 to 2020.

[1] Copernicus Climate Change Service (https://cds.climate.copernicus.eu/about-c3s).

1.1.1. Mean Temperature (Annual and Seasonal)

Figure 1 displays the annual mean temperature from 1950 to 2020. The Hajar Mountains, Musandam, and Dhofar mountains recorded lower mean temperatures compared to other regions. The mean temperature in these mountainous areas ranges between 12°C and 18°C, while the hillside areas show a mean temperature of about 24°C. The temperature rises to 26°C across most of Oman, with higher values (28°C) observed along the coastline between Muscat and Sur.

Long-term analysis identifies five different seasonal behaviors in Oman[2], classified as DJF, MA, MJ, JAS, and ON. This classification is used throughout the report. Figure 2, shows seasonal mean surface temperatures as per this classification. The Top-left map in Figure 2, presents the mean surface temperature for DJF (winter season), showing lower temperatures over the mountainous peaks and northern coasts due to the northeasterly monsoon.

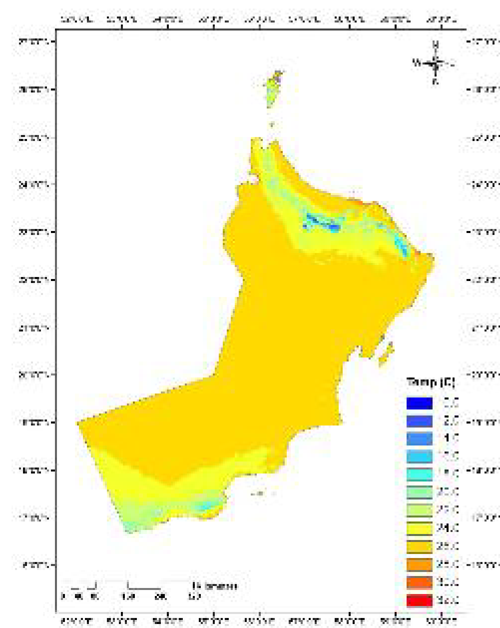

Figure 1: Annual mean temperature.

[2] Al Sarmi, S. and R. Washington (2011), Recent observed climate change over the Arabian Peninsula, J. Geophys. Res., 116, D11109, (doi:10.1029/2010JD015459).

During the MA season (spring), surface temperatures increase across all regions. The Hajar Mountains maintain lower temperatures due to higher elevations, while average temperatures of 26°C-27°C are observed in most regions (Top-middle map in Figure 2).

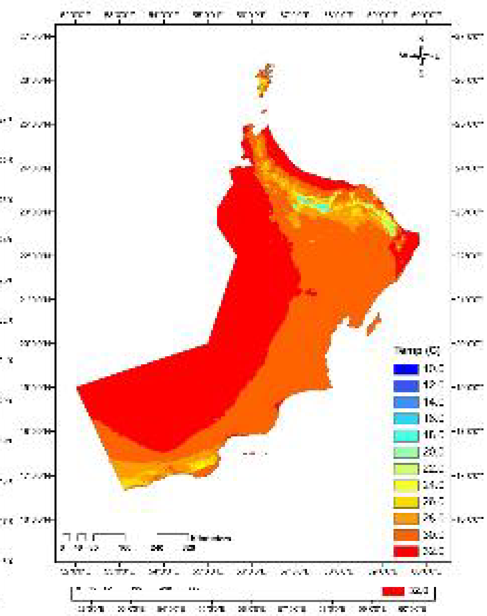

Figure 3: Annual Maximum Temperature.

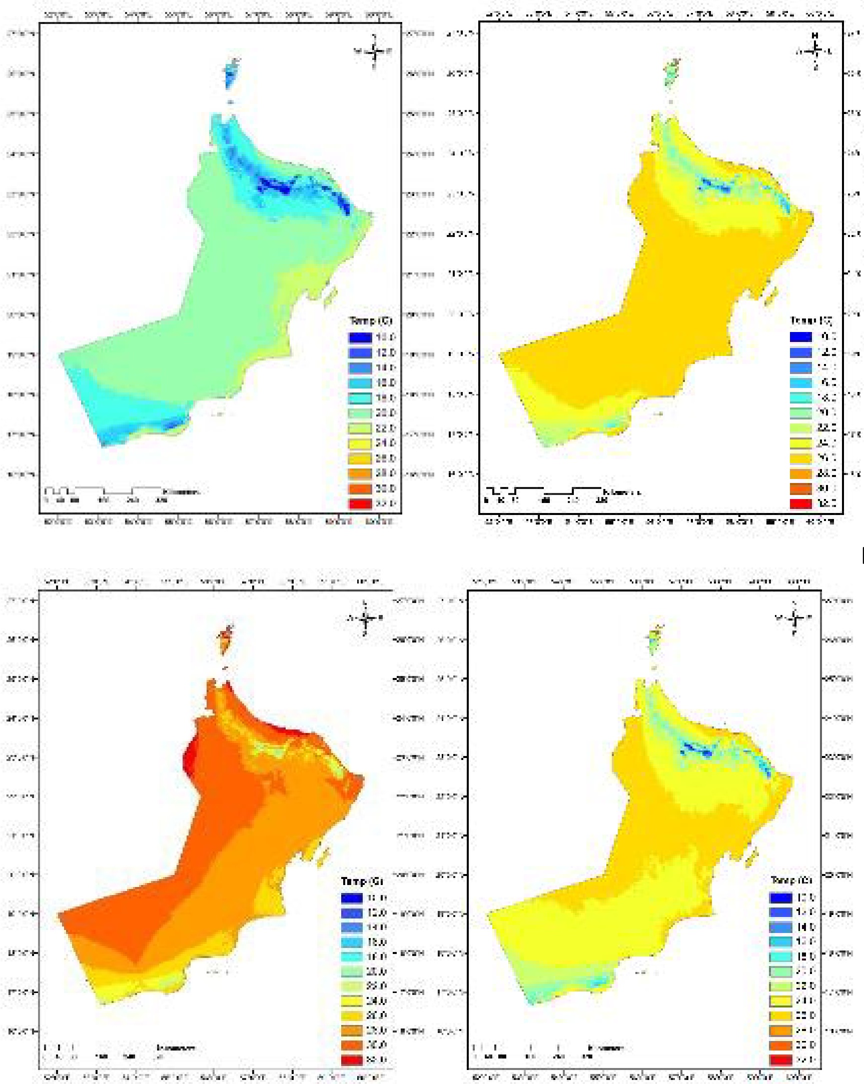

Figure 2: Mean temperature during December, January, and February (Top-Left), mean temperature during March and April (Top-Middle), mean temperature during May and June (Top-Left), and mean temperature during July (Bottom-Left, August, and September (Bottom-Right).

Bottom-left map in Figure 2, depicts the MJ season (pre-monsoon), showing a significant rise in temperatures, particularly in deserts and northern Oman. Mean temperatures reach 32°C, while mountain peaks remain around 24°C or lower. In the JAS season (monsoon), the monsoonal flow cools the southeastern coast and penetrates inland towards the Hajar

Mountains, lowering surface temperatures. During the ON season (autumn), temperatures decrease to levels similar to the MA season in the mountains and generally lower than the MA season elsewhere (Bottom-right map in Figure 2).

1.1.2. Annual Maximal Temperature

The maximum temperature significantly influences various social and economic activities and the development of convective clouds over the Hajar Mountains. Figure 3 illustrates the annual average maximum temperature in Oman from 1950 to 2020. Except for the mountainous regions (where temperatures are 26°C or lower), higher temperatures (28°C - 32°C) are observed in various parts of the country.

1.1.3. Annual Minimal Temperature

Figure 4 shows the annual minimum temperature from 1950 to 2020, with values ranging from 10°C to 23°C depending on geographical location and altitude. The difference between annual maximum and minimum temperatures is about 10°C in plain land and deserts and approximately 8°C over the mountain peaks.

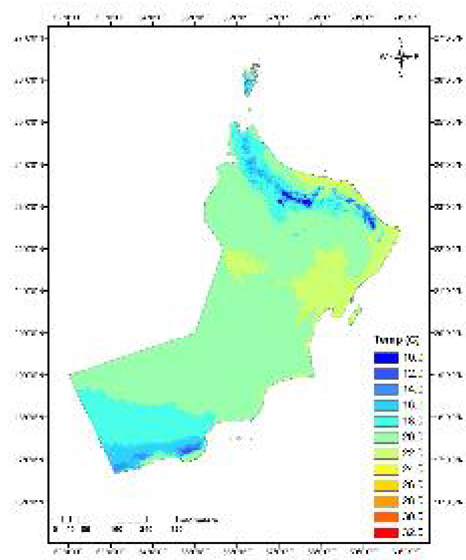

Figure 4: Annual Minimum Temperature.

1.2. Rainfall Pattern

1.2.1. Rainfall Regimes and Mechanisms

The Sultanate of Oman is characterized by an arid climate (Charabi, 2009), due to its location along the Tropic of Cancer in a zone dominated by the subsident limbs of the Northern Hemisphere Hadley Cell circulation[3]. However, Oman's coastal position at the southeastern end of the Arabian Peninsula and its high mountain range (Hajar Mountains) in the north contribute to significant annual mean rainfall in a few favoured areas[4].

Figure 5 shows the annual average precipitation during the period of 1950-2000. The highest rainfall amount, about 300 mm, is observed over the Hajar Mountains. The figure also shows the annual average rainfall over southern Oman due to the summer monsoon. There are four main mechanisms that bring rain to Oman, which will be detailed in the following subsections:

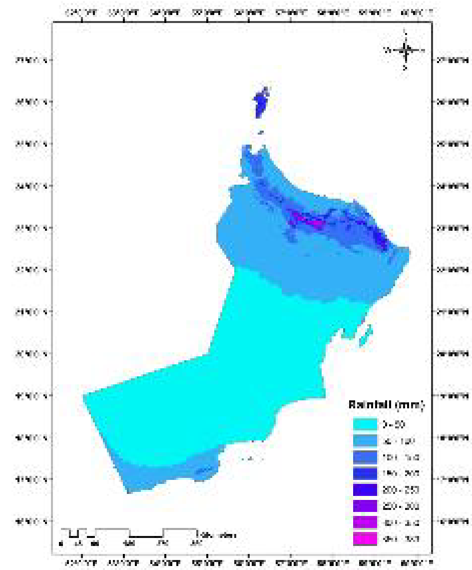

Figure 5: Annual average precipitation.

1.2.2. Mobile Upper Troughs

Mobile upper troughs, or westerly depressions, develop over North Africa and the Mediterranean in the strong zonal flow that occurs every winter in the Northern Hemisphere. These troughs/low-pressure systems are most active during December, January, and February but occasionally extend into March[5]. On average, there are four to five troughs a month. These troughs can bring widespread rain and flash floods, especially over the Hajar Mountains. However, it must be noted that such conditions are the exception rather than the rule, and many times the passage of an upper trough is identified only by patchy cloud and a wind shift accompanied by increasing surface pressure. If pressure rises significantly over the Arabian Peninsula, strong dust-rising northwesterly winds known as Shamal Winds will develop in the Oman interior, particularly over Dhahira, Dakhliya, and Al Wusta regions, occasionally extending as far south as southern Dhofar.

1.2.3. Khareef Drizzle

The monsoon, locally known as Khareef, starts at Salalah and adjoining mountain areas (southern coast of Oman) from the last week of June and ends around mid-September. In India and other parts of the tropics, the word monsoon is synonymous with heavy rain and thunderstorms; whereas in the southern part of Oman (Salalah and adjoining mountain) it brings persistent drizzle, light rain, and rarely thunderstorms. This activity turns the area green for over three months and attracts local and regional tourism. Rainfall over the Salalah plain and adjoining windward side of the mountain is normally in the form of drizzle mixed with light rain, seldom exceeding 5 mm in a 24-hour period. According to climate data from the Oman Meteorology Department, average rainfall during the monsoon period at Salalah airport is around 60 mm, with most of that (approximately 52 mm) falling during July and August. Average rainfall during this season over the windward side of the mountain is around 200 mm, whereas the leeward side of the mountain and north of it receive practically no rain (the Dhofar Mountain acts as a divide between the continuous drizzle during the monsoon and the thermal low on the other side of the mountain).

[3] Charabi Y (2009). Atmospheric Research, summer monsoon variability: Teleconexion to ENSO and IOD, vol.91 (2009) P.105–117 (https://doi.org/10.1016/j.atmosres.2008.07.006).

[4] Al-Maskari, J, 2006: Phd Thesis: Processes of convection and airflow over the Hajar Mountains. Leeds University, Leeds, UK.

[5] Ibid 4.

1.2.4. Tropical Cyclones

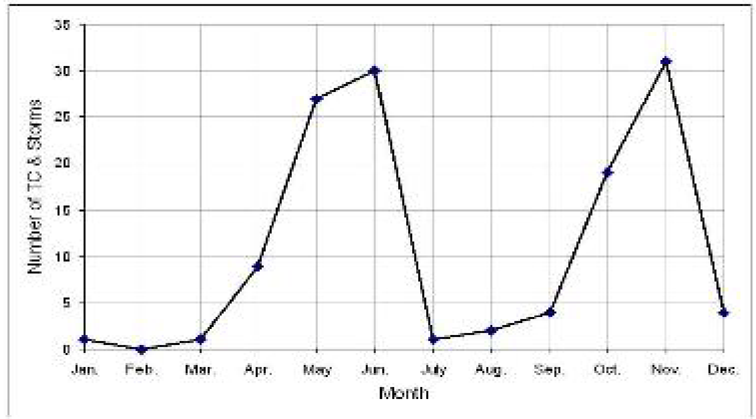

Figure 6: Frequency of Tropical Storms and Cyclones Affecting the Arabian Sea, 1801-2007.

Tropical cyclones are not uncommon over the Arabian Sea. However, many of these storms rarely reach the coastal areas of Oman with tropical cyclone intensity and from historical data they very rarely enter the Sea of Oman[6]. Tropical Cyclone Gonu was the first destructive tropical cyclone to affect Muscat after the 1890 cyclone. Tropical storms and cyclones are almost entirely confined to two cyclone seasons: the pre-monsoonal period (May-June) and post-monsoonal period (October-November)[7]. **Figure 6**, shows the frequency of tropical storms and cyclones affecting the Arabian Sea from 1801-2007. Most storms originate over the southeastern Arabian Sea near the Laccadive Islands, but some late-season storms start over the southeastern Bay of Bengal and move westwards across southern India, re-generating as they cross over the warm waters of the Arabian Sea.

1.2.5. Orographic Convective Rain

During the summer months, a mixing zone known as the Inter-Tropical Convergence Zone is found along the Omani coast from Dhofar to Sharqiya where desert and marine air converge. Usually, the overriding influence of the tropical continental air from the Arabian interior inhibits the formation of any summertime convection. However, the Hajar

[6] Al-Maskari, Juma, (2010). How the National Forecasting Centre in Oman Dealt with Tropical Cyclone Gonu. Indian Ocean Tropical Cyclones and Climate Change. Edited by Yassine Charabi. Springer. Netherlands (https://link.springer.com/book/10.1007/978-90-481-3109-9).

[7] Membery, D. A. 1985: A unique August cyclonic storm crosses Arabia. Weather, 40, 108–115

Mountains create an exception where local sea and land breezes converge[8], and strong insolation on elevated surfaces allows convection to break through the inversion (**Figure 7**).

According to Pedgley[9], the Inter-Tropical Convergence Zone reaches its northernmost position over Dakhliya and the Hajar Mountains in July and August, where a moist southeasterly flow from the Arabian Sea meets a dry northerly/northwesterly flow from the Arabian Gulf. The collision between the moist flow from the Arabian Sea and the sea breeze from the Sea of Oman triggers most convection over the Hajar Mountains. The dry northerly/north westerlies generally suppress convection. Intense heating over the Hajar Mountains causes convective clouds to form over the peaks, resulting in frequent short, intense thunderstorms, often with hail, mostly in the afternoon and early evening. The Hajar Mountains are crucial for enhancing convection and precipitation in northern Oman. Without these mountains, summer precipitation would be significantly reduced.

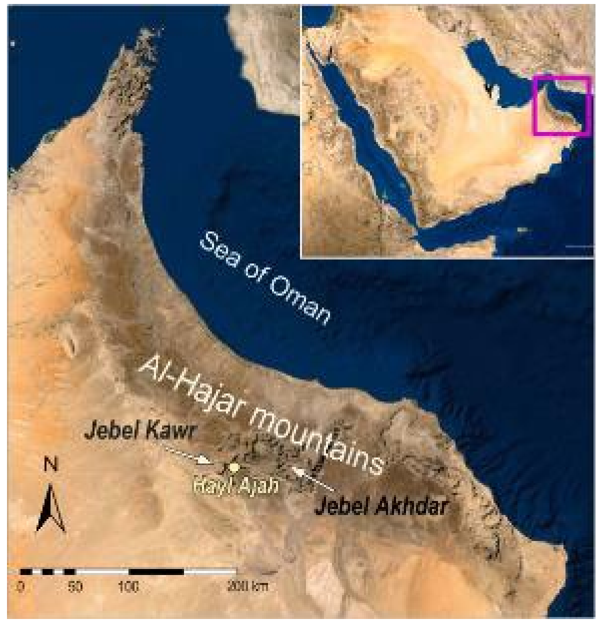

Figure 7: Localization of Al Hajar Mountain.

1.3. Wind Pattern

1.3.1. Southwest Monsoon Flow

Orographic convection over the Hajar Mountains is strongly linked with the southwest monsoon, characterized by winds blowing from the southwest over the Arabian Sea. These southwesterly winds are dominant during the monsoon period, especially from July to September. The monsoon spreads inland as far north as Fahud before being deflected to a southeasterly direction. Pilot balloon data show that the monsoon often reaches as far north as the Arabian Gulf. Based on these data, it is suggested that the depth of the monsoon at Salalah is between one and two kilometers. At Masirah Island, 500 m winds indicate that south westerlies are strongly dominant during the monsoon.

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[8] Pedgley, D. E., 1970: The Climate of Interior Oman. The Meteorological Magazine, Vol. 99, No. 1171, 29-37.

[9] Ibid 8.

1.3.2. Sea-Breeze

The sea-breeze is a diurnal phenomenon formed due to the temperature difference when the land surface is warmer than the adjacent body of water. Oman is surrounded by three bodies of water: The Arabian Gulf, the Sea of Oman, and the Arabian Sea. Sea-breezes can be generated from all three seas. The sea-breeze, especially from the Sea of Oman, contributes to summer orographic convection over the Hajar Mountains, though it is not as significant as the moist monsoon flow. The Hajar Mountains are affected mostly by sea-breezes originating from the adjacent Sea of Oman, with its coast running almost parallel to the mountains, and from the distant Arabian Gulf. Flow from the Arabian Gulf is influenced by the dominant dry northwesterly flow. In summer, the sea-breeze over the Arabian Gulf is deeper and wider than in winter, with penetration reaching 250 km inland along the UAE coast towards the Hajar Mountains. The summer sea-breeze is enhanced by the dominant northwesterly flow and flat terrain. Analysis of wind direction at Abu Dhabi airport showed evidence of southerly flow during July, indicating the extent of the monsoon flow.

1.3.3. Shamal Winds

The Shamal winds, meaning 'north' in Arabic, blow persistently in the summer, affecting the Arabian Gulf countries. They are caused by the heat low over Pakistan and Afghanistan and influenced by the Zagros Mountains in Iran, channeling strong winds over the Arabian Gulf. These dry northwesterly winds reduce visibility and can extend up to 1000 m vertically.

The Shamal brings hot, dry air in the summer and cold, dry air in the winter. The summer Shamal is less intense than the winter Shamal but still suppresses summer convection over the Hajar Mountains. Strong Shamal winds can reach as far as Masirah Island, reducing visibility and advecting dust into the Arabian Sea. The Shamal is typically strong during the day and decreases at night, except just above the surface, due to radiational cooling and a strong temperature inversion. **Figure 8** shows the annual average wind speed and direction (2002-2012) based on ECMWF reanalysis. The northern part of Oman experiences northwesterly winds, while the southeastern coast experiences east and northeasterly flow. During summer, due to the Indian monsoon, the southern part of Oman is dominated by southwesterly flow (**Figure 9**). Southerly and westerly flows occur in the northern part of Oman. In winter, northwesterly flow is present on the western side of the Hajar Mountains, and northeasterly flow on the other side. Northeasterly flow dominates the southern part of Oman during winter (**Figure 9**)[10]

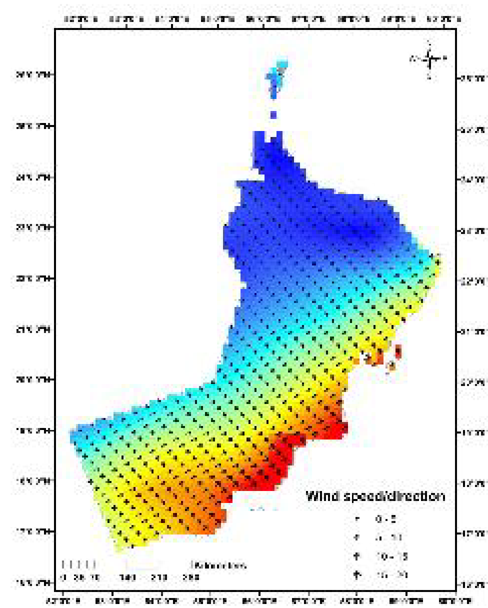

Figure 8: Annual Average Wind Speed and Direction.

[10] Ioannis Sempos (2023). Technical report on national downscaled climate change scenarios, National Adaptation Plan.

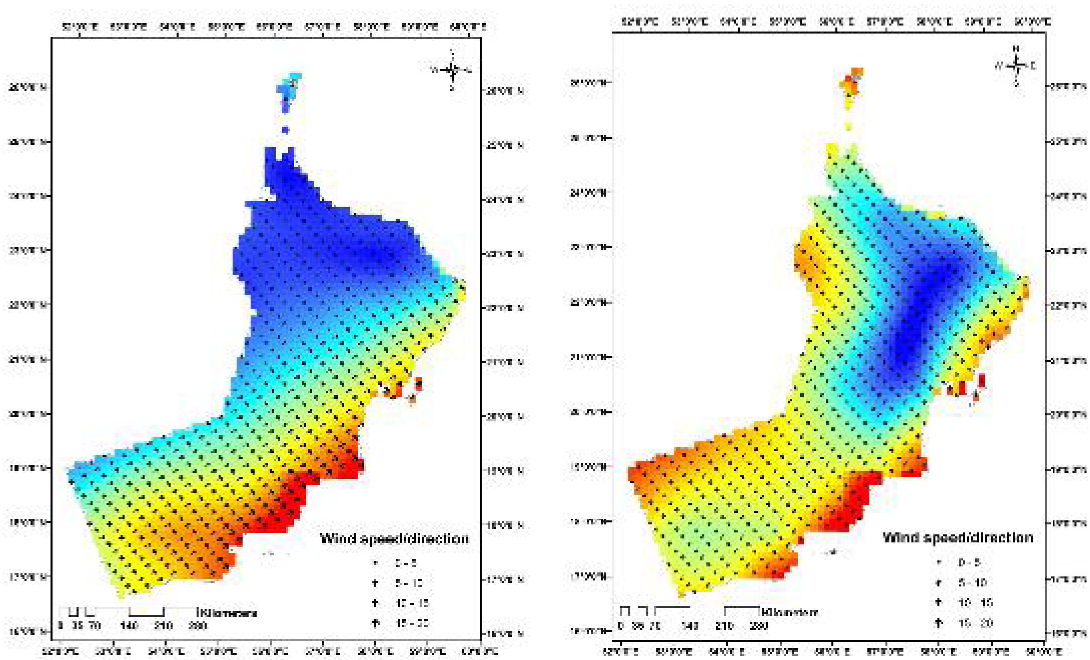

Figure 9: Average wind speed and direction during the summer season (JAS) (left) and during the winter season (DJF) (right).

1.4. Dust Pattern

Due to the dryness of the surface soil and wind conditions, Oman experiences dust storms from neighboring countries, as well as from its own deserts. Dust can be generated by downdrafts from severe thunderstorms and can travel hundreds of kilometers across the Arabian Peninsula towards Oman, especially during the passage of upper-level mobile troughs. Both summer and winter Shamal winds can bring dust, reducing visibility for days. Differential heating during summer also causes dust devils. The northern side of the Hajar Mountains is slightly protected, and visibility is better than on the southern side (**Figure 10**).

Dust storms impact health, the environment, the economy, aviation, and other sectors. **Figure 10**, shows the main dust sources surrounding the Arabian Peninsula[11]. Geostationary satellite images are essential for monitoring dust storm development and movement.

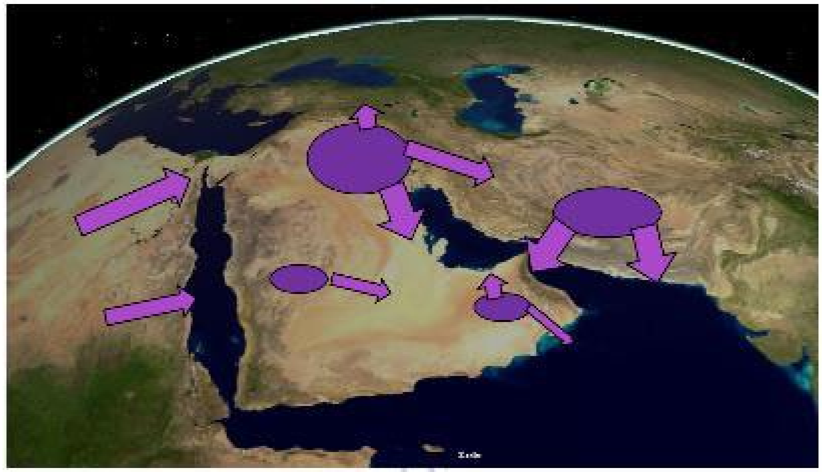

Figure 10: Dus

The orbital Multi-Angle Imaging Spectro Radiometer (MISR) is crucial for monitoring atmospheric aerosols. MISR, on NASA's Terra satellite launched on December 18, 1999, measures solar radiation reflected by the Earth's surface and atmosphere in various directions and spectral bands. This data is valuable for atmospheric sciences, climatology, and monitoring terrestrial processes. MISR consists of nine digital cameras gathering data in three spectral bands centered at 446, 558, and 867 nm. With a swath of about 380 km and spatial sampling up to 275 m per pixel, MISR achieves global coverage every 7 to 9 days at a resolution of 0.5 x 0.5 degrees. MISR data aids climatological studies on solar radiation flux, monitoring aerosol concentrations from natural and human sources, upper air winds, cloud cover, and land surface properties, including vegetation canopies, land cover types, and snow and ice fields. MISR's multi-spectral data can retrieve information about particle size, shape, single scattering albedo, and aerosol optical depth. Aerosol optical depth values exceeding 1 indicate heavy dust contamination. **Figure 11** shows annual aerosol optical depth patterns from MISR

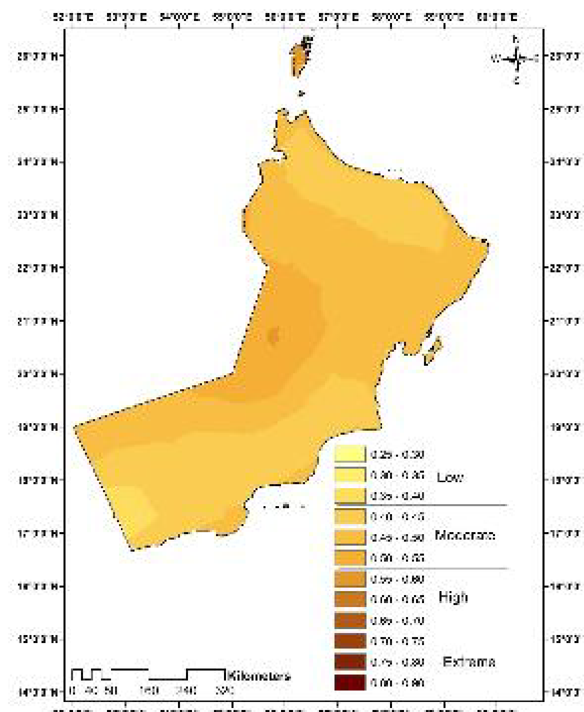

Figure 11: Annual Aerosol Optical Depth from MISR over Oman during 2009.

[11] Sultan Al-Yahyai, Yassine Charabi. (2014) Trajectory Calculation as Forecasting Support Tool for Dust Storms. Advances in Meteorology 2014, 16. (DOI:10.1155/2014/698359).

over Oman in 2009. **Figure 12**, show AOD during summer (JAS) and winter (DJA), respectively[12].

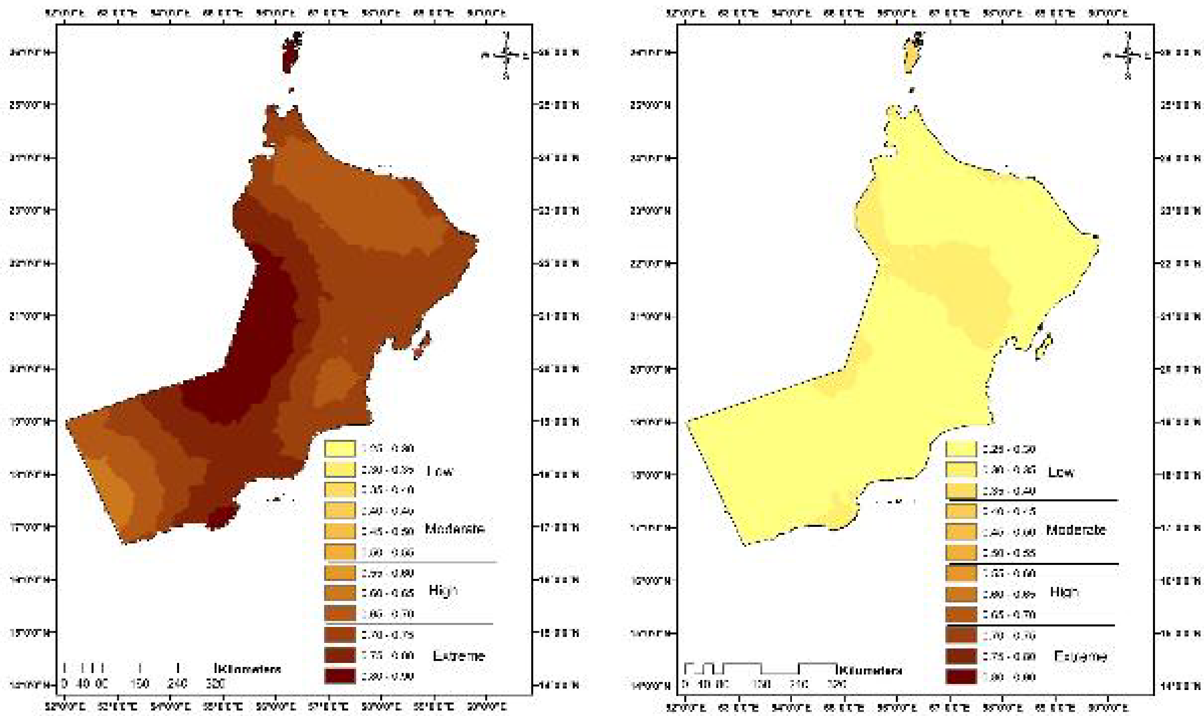

Figure 12: Patterns of Aerosol Optical Depth from MISR over Oman during summer (JJA 2009) (left) and winter (DJF 2009) (right).

1.5. Tropical Cyclones

1.5.1. Frequency of Tropical Cyclones in the Arabian Sea

From 1881 to 2019, a total of 236 tropical cyclones formed in the Arabian Sea. Of these, 134 made landfall, while 102 dissipated in the Arabian Sea or the Gulf of Aden. India has the highest frequency of Arabian Sea cyclones making landfall, with 26.7% of the total, nearly half of all land falling cyclones. Oman experienced 47 landfalls (19.9% of the total), with an additional 16 systems entering Omani coastal waters but dissipating at sea (between 60° and 64°

[12] Y. Charabi and A. Gastli, "Spatio-Temporal Assessment of Dust Risk Maps for Solar Energy Systems Using Proxy Data," Renewable Energy, Vol. 44, August 2012, pp. 23–31, (http://dx.doi.org/10.1016/j.renene.2011.12.005).

E)[13] (**Table 1**). The monthly distribution of Arabian Sea cyclones, as shown in **Table 2**, reveals that two to four cyclones typically occur every 15 years, with an exception from 1955 to 1984 when the rate doubled. Cyclone formation is particularly high in May–June and October–November. Half of all landfall events happened in the pre-monsoon season (13 in May, nine in June), and 30% in the post-monsoon season (five in September, six in October, and one in November). This pattern is consistent with the shorter record by Al-Maskari, Juma, (2010). Therefore, TCs in the Arabian Sea form primarily in two distinct seasons: pre-monsoon and post-monsoon.

Table 1: Distribution of Tropical Systems in the Arabian Sea (1881–2019)

Landfall country	Frequency	%
India	63	26.7
Oman	47	19.9
Pakistan	10	4.2
Somalia	7	3.0
Yemen [Socotra islands]	7	3.0
Terminates at Sea	102	43.2
Arabian Sea	96	40.7
Gulf of Aden	6	2.5
Total	236	100

Table 2: Monthly distribution of tropical systems in the Arabian Sea from 1881 to 2019.

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	%
1880–1894	0	0	0	1	2	5	0	0	0	1	3	0	12	5
1895–1909	0	0	0	1	4	5	2	0	0	5	1	1	19	8
1910–1924	0	0	0	1	3	2	0	0	0	2	1	0	9	6
1925–1939	1	0	0	0	5	7	0	0	0	2	5	4	24	9
1940–1954	0	0	0	4	2	6	0	0	1	4	5	1	23	10
1955–1969	0	0	0	0	6	5	3	2	1	5	5	2	29	13
1970–1984	0	0	0	1	6	9	4	0	2	1	2	1	24	21
1985–1999	0	0	0	0	3	6	0	0	1	6	5	3	24	10
2000–2014	0	0	0	0	5	9	0	0	4	6	7	1	32	12
2015–2019	0	0	1	0	2	4	0	0	1	5	1	4	18	6
Total	1	0	1	8	38	58	9	2	12	51	42	14	236	100
%	0	0	0	3	38	25	4	1	5	22	18	6	100	

[13] Al-Manji, S., Mitchell, G., & Al Ruheili, A. (2021). Arabian Sea Tropical Cyclones: A Spatio-Temporal Analysis in Support of Natural Hazard Risk Appraisal in Oman. *Agrometeorology*, edited by Ram Swaroop Meena, IntechOpen. DOI: 10.5772/intechopen.96961. Submitted: 05 October 2020, Reviewed: 02 March 2021, Published: 03 April 2021.

1.5.2. Trajectory assessment of cyclonic systems in the Arabian Sea that impact Oman's coastline

1.5.2.1. Track Classification

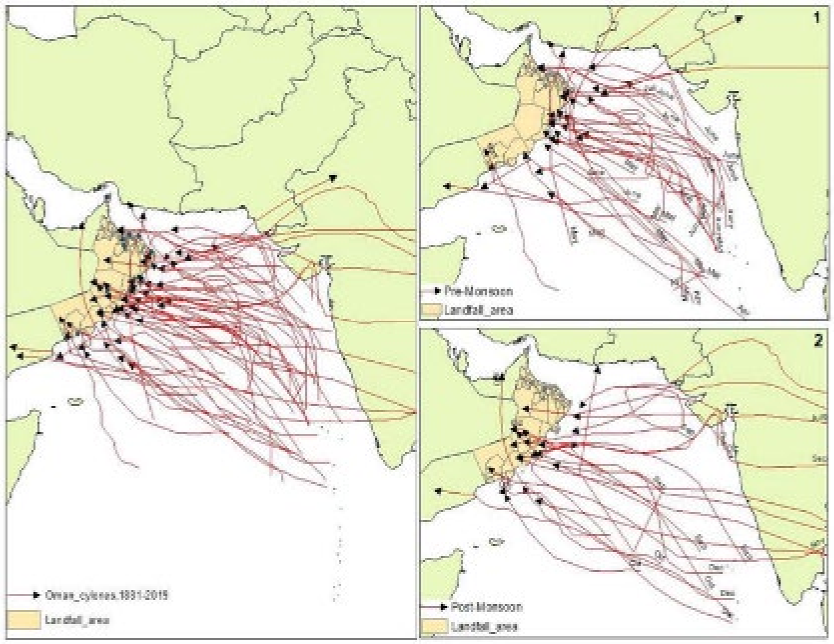

Figure 13: Seasonal distribution of Arabian Sea cyclone tracks landing in Oman, 1881–2019: (1) pre-monsoon, (2) post-monsoon.

Analysis of cyclone paths (**Figure 13**) reveals distinct seasonal patterns between pre- and post-monsoon periods. Pre-monsoon cyclones originate exclusively in the Arabian Sea, with their genesis points shifting from southeast to northeast from May through July. Monthly track variations are observed, with May cyclones generally moving southwest, while June and July cyclones tend northwest, some curving northeast towards India in June[14].

Post-monsoon cyclone origins show greater spatial diversity. September sees most formations in the northeast Arabian Sea, transitioning to southeast and south from October to December. Some cyclones form in the Bay of Bengal, traversing India to enter the Arabian Sea. Typical post-monsoon tracks progress from westward in September to southwestward towards the Gulf of Aden and Horn of Africa from October to December, with some November systems recurving towards India. For Oman-land falling storms, seasonal track variations are evident. Pre-monsoon May cyclones often target the coast between Masirah Island and Salalah, while June systems favor central and northeast Oman, from Masirah Island to Ras Al Had. Historical exceptions include a May 1898 cyclone crossing from Ras Madrakah to north Oman, and a June 1885 system moving to the southeast coast before entering the Gulf of Aden off Yemen. Post-monsoon tracks show a progression: September cyclones typically affect central Oman between Masirah Island and Ras Madrakah, while October to December systems increasingly tend towards Salalah in southeast Oman[15].

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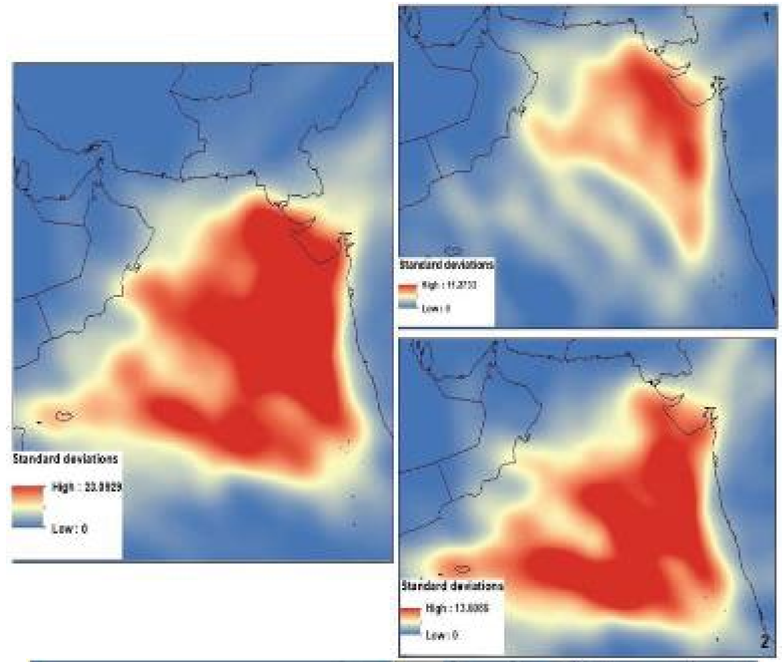
[14] Ibid 12.

[15] Ibid 12.

1.5.2.2. Density Analysis of Arabian Sea Cyclone Paths

Kernel Density Estimation is employed to evaluate cyclone track distribution in the Arabian Sea, highlighting areas of high occurrence. **Figure 14** illustrates a concentrated area of tracks spanning 15–25° N and 60–73° E in the Arabian Sea. Pre-monsoon patterns (**Figure 14** (1)) show a high density of cyclones moving towards northwest India (Gujarat), while post-monsoon patterns (**Figure 14** (2)) indicate higher density in the southern and southeastern Arabian Sea. **Figure 15** depicts the Kernel Density Estimation for cyclones making landfall in Oman. Pre-monsoon tracks (**Figure 15**(1)) show high density near Ras Madrakah on Oman's mid-eastern coast. Post-monsoon tracks (**Figure 15** (2)) concentrate more towards Salalah in the southeast[16].

Figure 16 presents monthly Kernel Density Estimation analysis for Oman-land falling cyclones. May sees high density near Ras Madrakah and some activity near Salalah. June maintains high density in mid-Oman and near Ras Al Had. Post-monsoon patterns show highest density near Ras Madrakah in September, shifting towards Salalah in October[17].



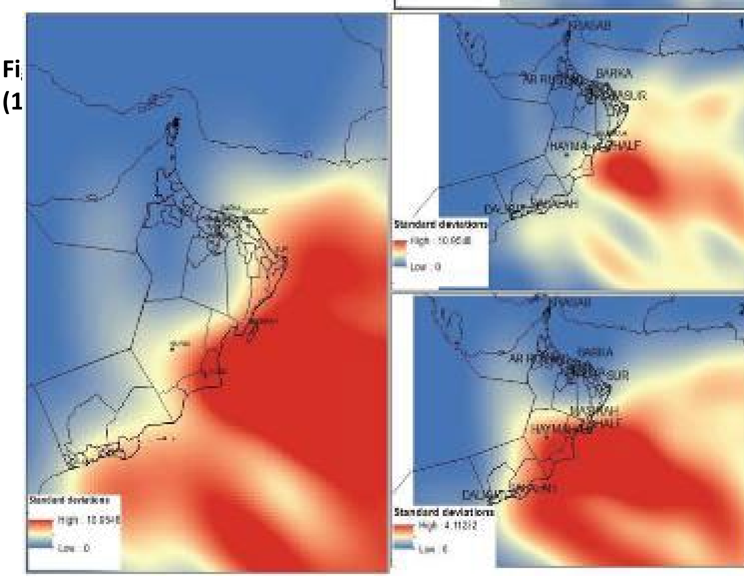


Figure 15: Seasonal KDE of Oman-land falling cyclone tracks, 1881–2019: (1) pre-monsoon, (2) post-monsoon.

[16] Ibid 12.

[17] Ibid 12.

1.5.2.3 Directional Analysis of Arabian Sea Storm Tracks

Linear Direction Mean results are presented in Table 3 and **Figure 17**. For all Arabian Sea storms (**Figure 17**(1)), the Linear Direction Mean points northwest towards Oman and Iran, with a mean angle of 127.8° and average length of 1480 km. Pre-monsoon Linear Direction Mean is northward towards Pakistan (120.4°), while post-monsoon Linear Direction Mean is northwest towards northeast Oman (136.4°).

Oman-land falling tracks (**Figure 17** (2)) show a mean direction of 157.8° towards the mid-east coast south of Masirah Island, averaging 2169 km in length. Pre-monsoon tracks average 146.0° towards Masirah Island (1827 km), while post-monsoon tracks average 157.9° towards Ras Madrakah (2361 km).

Figure 17 (3), illustrate seasonal and monthly LDM patterns for Oman-landfalling cyclones. May storms typically track towards Ras Madrakah, while June storms, originating further north and east, move towards northwest Arabian Sea and Muscat with longer paths. Post-monsoon patterns show September storms heading towards Masirah Island and October storms towards Salalah[18].

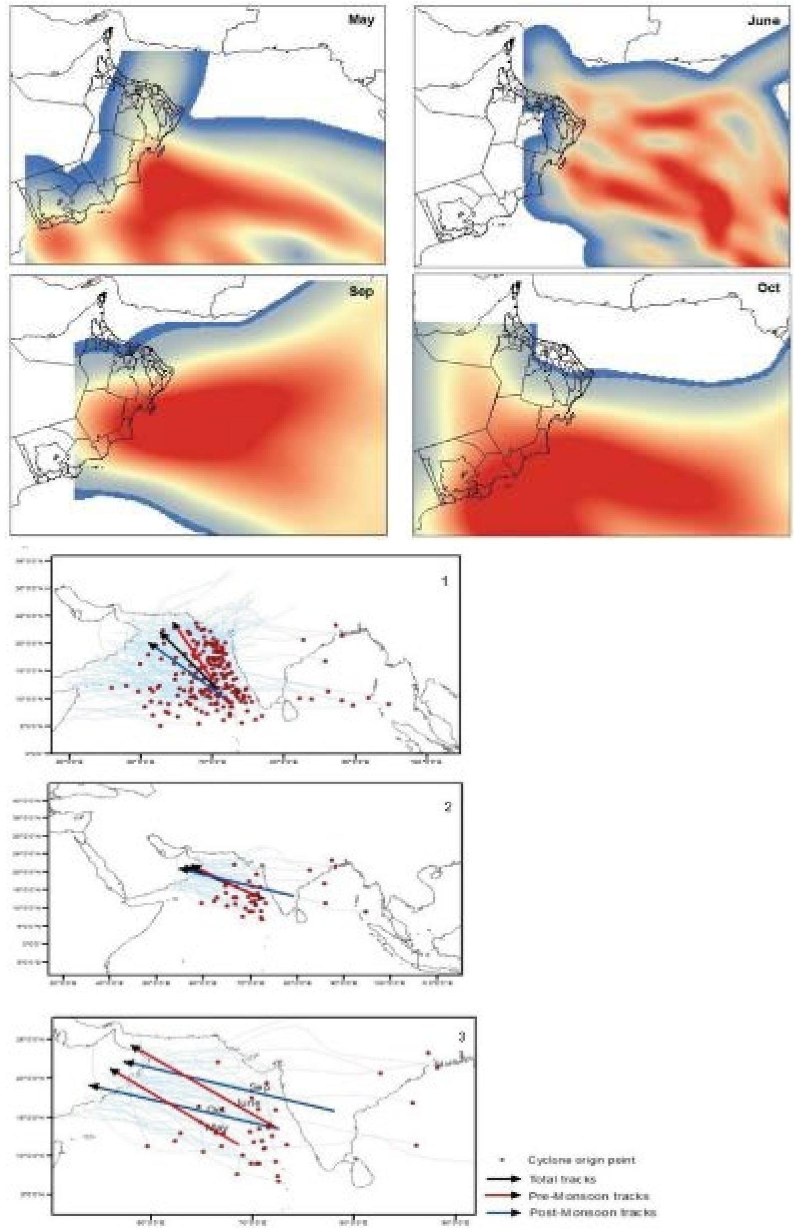


Figure 17 : Directional trend analysis of Arabian Sea cyclonic systems: (1) comprehensive track assessment, (2) Oman landfall-specific trajectories, and (3) seasonal breakdown of Oman-impacting cyclone paths for pre- and post-monsoon periods.

2. Historical Climate Trend

2.1. Temperature Trends

2.1.1. Time Series Analysis of Temperature Trends

[18] Ibid 12.

Figure 18, illustrates an upward trend in Oman's annual mean temperature starting around 1980[19]. This trend persists despite natural variability, shown by both the annual mean temperature and its 5-year smoothed line. Comparing the average temperature from 2011-2021 (27.90°C) to 1901-1910 (26.83°C) shows a 1.06°C increase. The 5-year smoothed value for 2021 is 28.06°C, 1.39°C higher than in 1910 (26.67°C)[20].

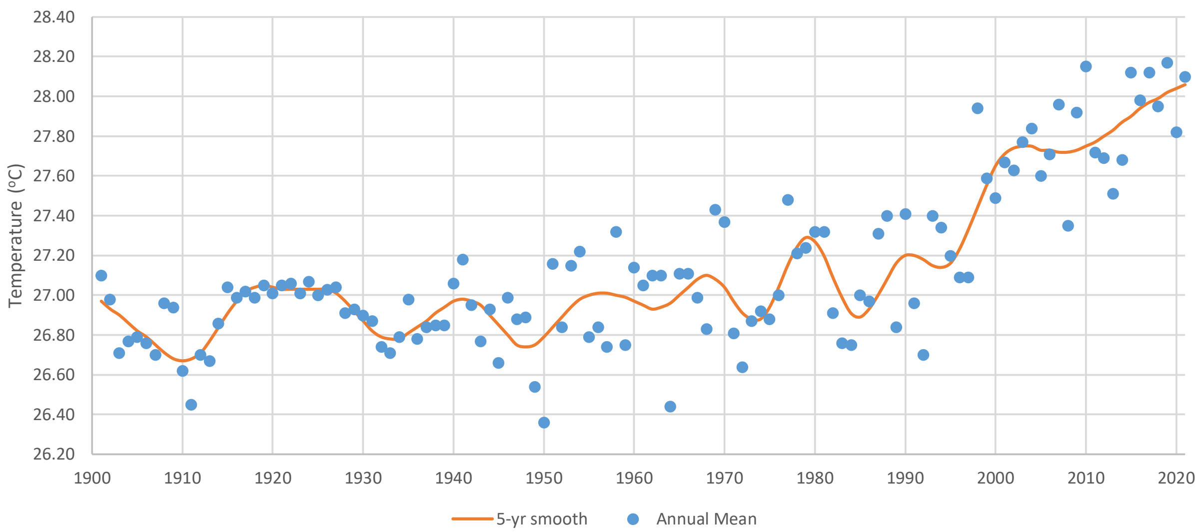


Figure 18: Observed Annual Mean Temperature of Oman (1901-2021).

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[19] Ioannis Sempos (2023). Technical report on national downscaled climate change scenarios, National Adaptation Plan.

[20] The historical climate data used in this study were obtained from the Climatic Research Unit (CRU) at the University of East Anglia. The data, with a resolution of 0.5° x 0.5° (50km x 50km), provide detailed insights into climate variations over time. The datasets were downloaded from the following websites:
https://crudata.uea.ac.uk/cru/data/hrg/
https://data.ceda.ac.uk//badc/cru/data/cru_ts/
Additionally, CRU data from the Climate Change Knowledge Portal (CCKP) of the World Bank Group were accessed and integrated for Oman, available at https://climateknowledgeportal.worldbank.org/country/oman.
The CRU TS (Climatic Research Unit gridded Time Series) is a widely used observational climate dataset, providing data on a 0.5° x 0.5° longitude grid.

To minimize the influence of natural variability and better assess temperature increases, the average temperatures over extended periods are compared. The trends in Oman's monthly minimum, mean, and maximum temperatures are examined across four distinct periods: 1901-1930, 1931-1960, 1961-1990, and 1991-2020. This approach highlights temperature changes over time. The temperature in Oman typically rises from January to June, peaks, and then declines until December. Recent trends show an increase in temperature compared to historical data. From 1991-2020, the monthly minimum temperature increased by an average of 0.87°C compared to 1901-1930, with the smallest increase in July (0.61°C) and the largest in October (1.07°C) (**Figure 19**)[21].. The monthly mean temperature rose by 0.74°C from 1991-2020 compared to 1901-1930. The smallest increase was in July (0.49°C), and the largest in October (0.91°C) The maximum temperature increased by an average of 0.61°C from 1991-2020 compared to 1901-1930, with the most significant rise in February (0.77°C) and the smallest in July (0.38°C) (**Figure 20**).

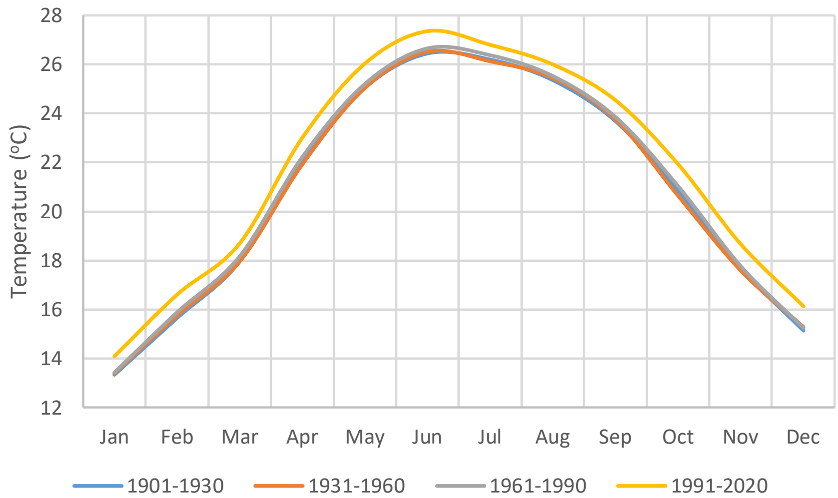


Figure 20: Trend of Monthly Minimum Temperature of Oman.

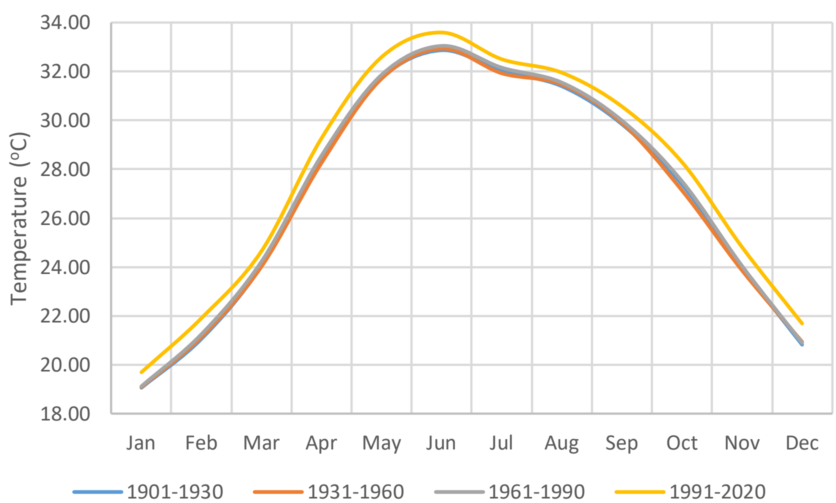


Figure 19: Trend of Monthly Maximum Temperature of Oman.

Climate trends must be analyzed within the context of natural variability, which includes fluctuations in temperature and precipitation. These can result from internal climate variability or non-human periodic events like volcanic eruptions. Human-induced factors, such as greenhouse gas emissions and land surface changes, also impact the climate system. Identifying climate change signals involves distinguishing these anthropogenic effects from natural variability. To understand trends, the analysis focuses on differences in variability, trends, and significance over 70-, 50-, and 30-year intervals. This approach reveals how forced changes intensify over natural variability. The statistical significance

[21] Ioannis Sempos (2023). Technical report on national downscaled climate change scenarios, National Adaptation Plan.

of observed trends is evaluated using p-values. A p-value of 0.05 or less indicates a significant trend, with smaller p-values reflecting greater significance. Specific thresholds are applied to interpret p-values:

- Below 0.001: highly significant trend
- Between 0.001 and 0.05: significant trend
- Above 0.05: statistically insignificant

For the period 1951-2020, the trend shows a significant increase of 0.20°C per decade. This trend continues for 1971-2020, with an increase of 0.22°C per decade. For 1991-2020, the trend is slightly lower at 0.19°C per decade, but still significant. These findings suggest a sustained and significant warming trend in Oman, likely not due to natural variability alone (**Figure 21**).

Table 3 provides a detailed summary of temperature trends in Oman, showcasing decade-wise changes in mean, maximum, and minimum temperatures. The table also assesses the statistical significance of these trends. Corresponding time-series data for maximum and minimum temperature trends are illustrated in **Figure 22** and **Figure 23**.

Table 3: Temperature Trends in Oman and Statistical Significance.

Variable	Period	Trend / decade	p-value	Significance
Annual Mean Temperature	1951-2020	+0.20°C per decade	3.98e-20	Statistically high significant
	1971-2020	+0.22°C per decade	6.03e-11	Statistically high significant
	1991-2020	+0.19°C per decade	0.0017	Statistically significant
Annual Maximum Temperature	1951-2020	+0.23°C per decade	5.40e-19	Statistically high significant
	1971-2020	+0.28°C per decade	2.97e-11	Statistically high significant
	1991-2020	+0.20°C per decade	0.0067	Statistically significant
Annual Minimum Temperature	1951-2020	+0.29°C per decade	8.22e-23	Statistically high significant
	1971-2020	+0.26°C per decade	1.53e-10	Statistically high significant
	1991-2020	+0.20°C per decade	0.0013	Statistically significant

A key observation from the data is the statistically highly significant trend that both maximum and minimum temperatures are increasing at a faster rate compared to the mean temperature. Specifically:

For maximum temperature, the rate of increase is 0.23°C per decade for the period 1951-2020, rising to 0.28°C per decade for 1971-2020.

For minimum temperature, the rate of increase is 0.29°C per decade for 1951-2020, and 0.26°C per decade for 1971-2020.

These findings confirm the overall trend of rising temperatures while highlighting the varying rates of change among different temperature metrics.

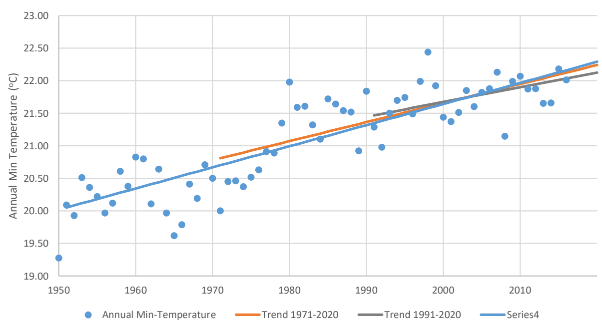


Figure 23: Trend of Annual Minimum Temperature of Oman.

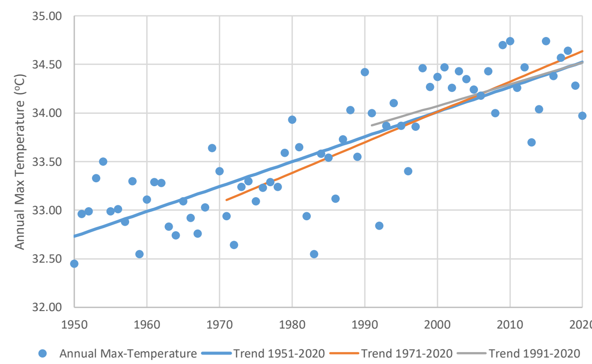


Figure 22: Trend of Annual Maximum Temperature of Oman.

2.1.2. Spatial Trends in Temperature Changes across Oman

In **Table 4**, a detailed comparison between the decades 2011-2021 and 1901-1910 is presented, highlighting the progressive rise in average annual minimum, mean, and maximum temperatures. This table provides a data-driven snapshot, offering a clear perspective on the historical temperature shifts that have shaped Oman's climate. The differential increase in the average annual mean temperature across Oman's regions is striking. For instance, Dhofar recorded an increase of 0.89°C, whereas Al Wusta experienced a slightly steeper rise of 1.01°C. The ascent is even more pronounced in regions like Musandam, with an uptick of 1.68°C, Al Batnah at 1.45°C, and Al Dhahira at 1.43°C. Muscat, the capital, also registered a significant increase of 1.27 °C. **Table 5** a detailed comparative analysis is presented between the periods 1991-2020 and 1901-1930, highlighting the incremental increases in monthly minimum, mean, and maximum temperatures across various regions in Oman. This table provides a comprehensive empirical overview of long-term climatic changes.

Table 4: Increase of Average Annual Minimum, Mean and Maximum Temperatures of Oman's Governorates in 2011-2021 compared to 1901-1910.

Governorates	Increase of Average Annual Min T (°C)	Increase of Average Annual Mean T (°C)	Increase of Average Annual Max T (°C)
Muscat	1.43	1.27	1.12
Al Batnah	1.58	1.45	1.33
A Sharqiya	1.23	1.09	0.96
A Dakhliya	1.35	1.26	1.16
Al Dhahira	1.53	1.43	1.33
Al Wusta	1.04	1.01	0.99
Dhofar	0.89	0.89	0.89
Musandam	1.82	1.68	1.55

The variations in the average increase of monthly mean temperatures across different regions of Oman are notable. In Dhofar, the average monthly mean temperature has risen by 0.66°C, while in Al Wusta, the increase is slightly lower at 0.60°C. Temperature rises more sharply in other regions, with Musandam witnessing an increase of 1.24°C, Al Batnah at 0.98°C, and Al Dhahira at 0.97°C. The capital, Muscat, has also experienced a discernible rise, with temperatures increasing by 0.83°C.

These variations in temperature increases across Oman indicate diverse climatic responses to global warming. Dhofar and Al Wusta show relatively modest increases, potentially due to geographical and climatic factors that moderate temperature rises. In contrast, Musandam has experienced the highest increase, suggesting significant climatic shifts. Al Batnah and Al Dhahira have seen substantial temperature increases, close to each other, pointing towards similar climatic influences. As the capital city, Muscat's notable rise underscores the urban heat island effect and other anthropogenic factors contributing to temperature increments.

Table 5: Increase of Monthly Minimum, Mean and Maximum Temperatures of Oman's Regions in 1991-2020 compared to 1901-1931.

Governorates	Increase of Monthly Min T (°C) in period 1991-2020 compared to 1901-1930			Increase of Monthly Mean T (°C) in period 1991-2020 compared to 1901-1930			Increase of Monthly Max T (°C) in period 1991-2020 compared to 1901-1930		
	Average	Max	Min	Average	Max	Min	Average	Max	Min
Muscat	1.27	1.53	0.97	0.83	1.09	0.61	0.39	0.75	0.17
Al Batnah	1.28	1.54	1.02	0.98	1.22	0.73	0.69	1.02	0.35
A Sharqiya	1.10	1.35	0.70	0.71	0.95	0.38	0.31	0.66	0.03
A Dakhliya	1.09	1.32	0.86	0.83	1.04	0.65	0.56	0.85	0.38
Al Dhahira	1.17	1.43	0.89	0.97	1.23	0.70	0.77	1.02	0.48
Al Wusta	0.76	0.94	0.46	0.69	0.86	0.39	0.61	0.79	0.32
Dhofar	0.67	0.90	0.34	0.66	0.90	0.34	0.66	0.90	0.34
Musandam	1.43	1.82	1.01	1.24	1.62	0.69	1.04	1.50	0.38

2.2. Precipitation Trends

An examination of the period 1991-2020 reveals a varied picture of precipitation compared to earlier decades. Most notably, precipitation in these recent years was generally lower than in the period 1901-1930, except for the month of March. The average reduction between these two periods amounted to 0.86 mm, ranging from a decrease of 3.73 mm to an increase of 0.91 mm.

The complexity of the trends continues when comparing other periods:

- In several months from the years 1991-2020, such as February, April, May, June, September, and October, precipitation levels were similar to those of the 1931-1960 period (**Figure 24**).
- In certain instances, such as November and December (with December specifically compared to 1961-1990), the period of 1991-2020 actually experienced higher precipitation levels than both the 1931-1960 and 1961-1990 intervals (**Figure 24**).

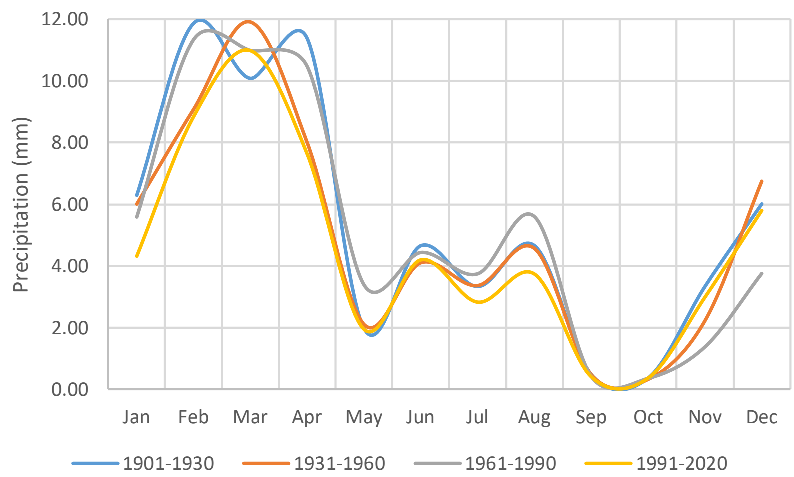


Figure 24: Trend of monthly Precipitation of Oman,

These findings illustrate that identifying a specific decreasing trend in precipitation is more complex and elusive compared to the more discernible trends observed in temperature. The intricacies and variations across different periods underscore the challenges in drawing definitive conclusions about precipitation patterns, highlighting the multifaceted nature of climate analysis in the region (**Figure 25**).

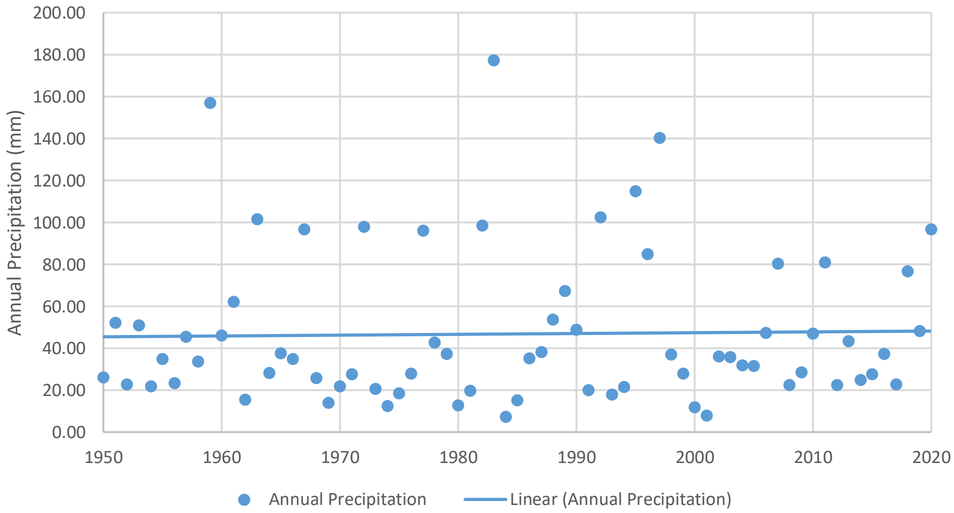
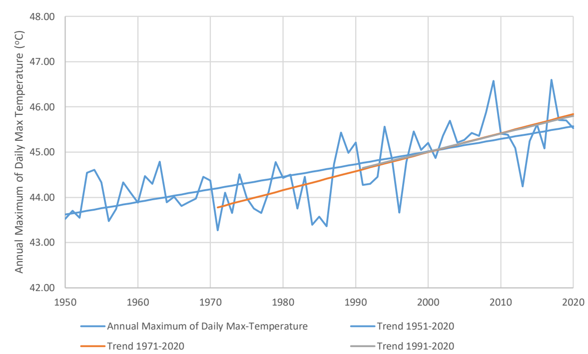


Figure 25: Trend of Annual Precipitation of Oman.

2.3. Extreme Temperature Events

Analyzing trends in extreme temperature events over periods of 70, 50, and 30 years (1951-2020, 1971-2020, and 1991-2020) provides valuable insights into climatic changes in Oman. The key variables examined include the maximum of daily maximum temperature, minimum of daily minimum temperature, the number of tropical nights (with minimum temperatures exceeding 20°C), and days with a Heat Index exceeding 35°C. The statistical significance of these trends was assessed using p-values, with p-values below 0.001 considered highly significant, those between 0.001 and 0.05 considered significant, and those above 0.05 deemed not significant.



The results reveal that the maximum of daily maximum temperature increased by 0.28°C per decade from 1951-2020 (highly significant, p = 4.08e-13), 0.38°C per decade from 1971-2020 (highly significant, p = 3.01e-10), and 0.36°C per decade from 1991-2020 (significant, p = 0.0016) (**Figure 26**). The minimum of daily minimum temperature rose by 0.37°C per decade from 1951-2020 (highly significant, p = 1.99e-07), 0.24°C per decade from 1971-2020 (significant, p = 0.025), and 0.07°C per decade from 1991-2020 (not significant, p = 0.716) (**Figure 27**). The number of tropical nights increased by 5.83 nights per decade from 1951-2020 (highly significant, p = 1.48e-19), 5.34 nights per decade from 1971-2020 (highly significant, p = 1.57e-08), and 5.10

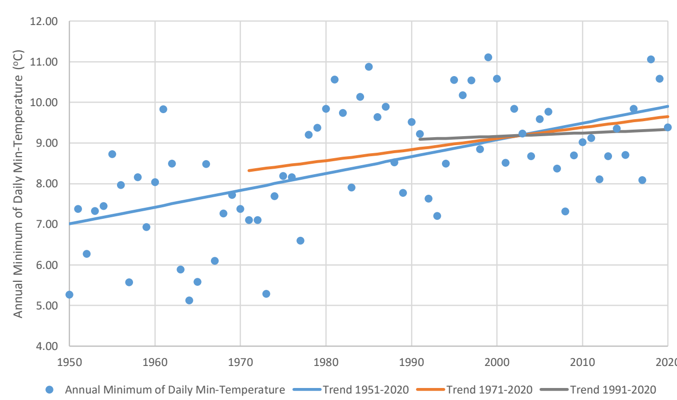


Figure 27: Trend of Annual Minimum of Daily Min-Temperature of Oman.

nights per decade from 1991-2020 (significant, $p = 0.001$) (**Figure 28**). Additionally, the days with a Heat Index exceeding 35°C rose by 6.13 days per decade from 1951-2020 (highly significant, $p = 1.10e-19$), 6.57 days per decade from 1971-2020 (highly significant, $p = 1.54e-11$), and 7.67 days per decade from 1991-2020 (highly significant, $p = 5.75e-05$) (**Figure 29**).

Overall, Oman has experienced statistically significant increases in extreme temperature events over the past seven decades. The consistent rise in maximum and minimum temperatures, the number of tropical nights, and days with a high Heat Index highlights the impact of climate change on the region. Continued monitoring and research are essential to address these challenges.

3. Climate Projection

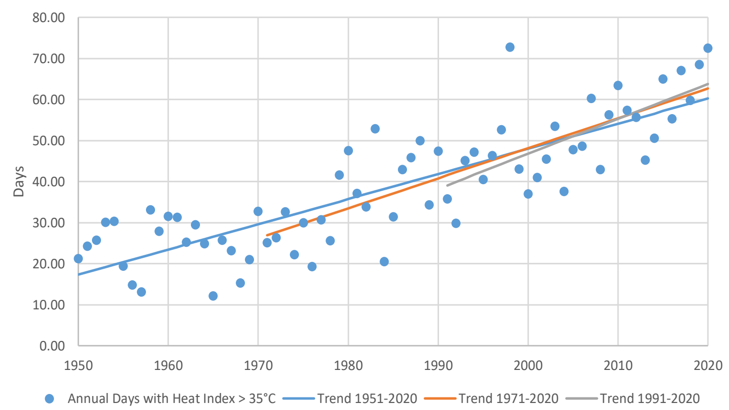


Figure 29: Annual Days with Heat Index exceeding 35oC of Oman.

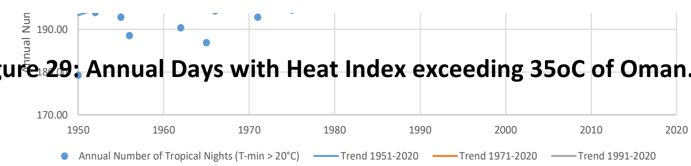


Figure 28: Trend of Annual Number of Tropical Nights (T-min>20oC) of Oman.

The climate projection data used in this study comes from the global climate model compilations of the CMIPs, administered by the World Climate Research Program. Specifically, the data is from CMIP6, the sixth phase of CMIPs, with a resolution of 1.0° x 1.0° (100km x 100km). CMIPs provide foundational data for the IPCC Assessment Reports, with CMIP6 contributing to the IPCC's Sixth Assessment Report.

This study employs scenarios to depict a range of conceivable climate futures, showing potential consequences of various pathways without assuming their likelihood. Over the past three decades, the scenario approach has evolved from a climate-centric framework to one focused on societal development, offering insights into a range of plausible climate outcomes. In CMIP6, these scenarios are presented as SSPs, replacing the RCPs used in CMIP5. These climate projections are shaped by new emissions and land-use scenarios based on integrated assessment models (IAMs) that reflect future societal development pathways. The transition from RCPs to SSPs and the updated models and emissions data differentiate CMIP6 projections from CMIP5.

CMIP6 introduces five primary scenarios, reflecting possible societal development and policy directions to achieve specified radiative forcing targets by the end of the century:

- SSP1-1.9: The most optimistic scenario, aiming for a radiative forcing of 1.9W/m² by 2100, aligning with the Paris Accord target.
- SSP1-2.6: A scenario supporting increased sustainability with severe global emissions cuts, reaching net-zero just after 2050.
- SSP2-4.5: A 'middle of the road' scenario where emissions linger at current levels before declining around mid-century but failing to reach net-zero by 2100.
- SSP3-7.0: A pathway depicting an increasingly competitive global landscape with emissions doubling current levels by 2100.
- SSP5-8.5: A future leaning on intensified fossil fuel usage, marked by global market integration and technological advancement.

These scenarios illustrate potential trajectories rather than exclusive pathways to achieve specific forcing levels. In this report, three distinctive scenarios from the list were rigorously analyzed, each portraying a unique future trajectory of climate change impacts:

- SSP1-1.9: Representing the optimistic pathway, this scenario aligns with the fulfillment of the Paris Agreement's target, aiming to limit global warming to 1.5°C above pre-industrial levels.
- SSP2-4.5: This scenario reflects the current landscape of mitigation policies and NDCs, embodying a moderate outcome in line with existing commitments.
- SSP5-8.5: Depicting a worst-case hypothetical scenario, this one assumes minimal to no mitigation action, leading to the most severe potential consequences.

These three scenarios collectively span the spectrum of possible climate impacts, from the optimistic assumption of successful global efforts following the Paris Agreement's CO2 pathway, to a realistic median scenario considering ongoing policies and NDCs, and a pessimistic extreme envisioning minimal action against climate change. This diverse range of scenarios is crucial given the inherent uncertainty in future projections, ensuring a comprehensive analysis that can inform robust policy decisions.

The CCKP-CMIP6 collection includes data from up to 31 models across the SSPs. For this report, the multi-model ensemble was employed, encapsulating the range and distribution of the most credible projected changes in the climate system for the selected SSP. This comprehensive approach fosters a nuanced understanding of possible futures and the complex interplay between societal development, policy decisions, and climate change.

3.1. Temperature Projections

3.1.1. Early Century (2020-2039)

In the early century period from 2020 to 2039, climate projections under different emission scenarios predict varying degrees of temperature increases across Oman (**Figure 30**):

- SSP1.9 (Low emissions): Mean, maximum and minimum temperatures likely to increase by 0.3°C in northern and western Oman.
- SSP4.5 (Intermediate emissions): Mean and maximum temperatures likely to increase by 0.3°C throughout Oman. Minimum temperature likely to increase by 0.4°C in most areas.
- SSP8.5 (High emissions): Mean temperature likely to increase by 0.4°C in northeast. Maximum temperature likely to increase by 0.3°C in northeast. Minimum temperature likely to increase by 0.5°C in northeast.

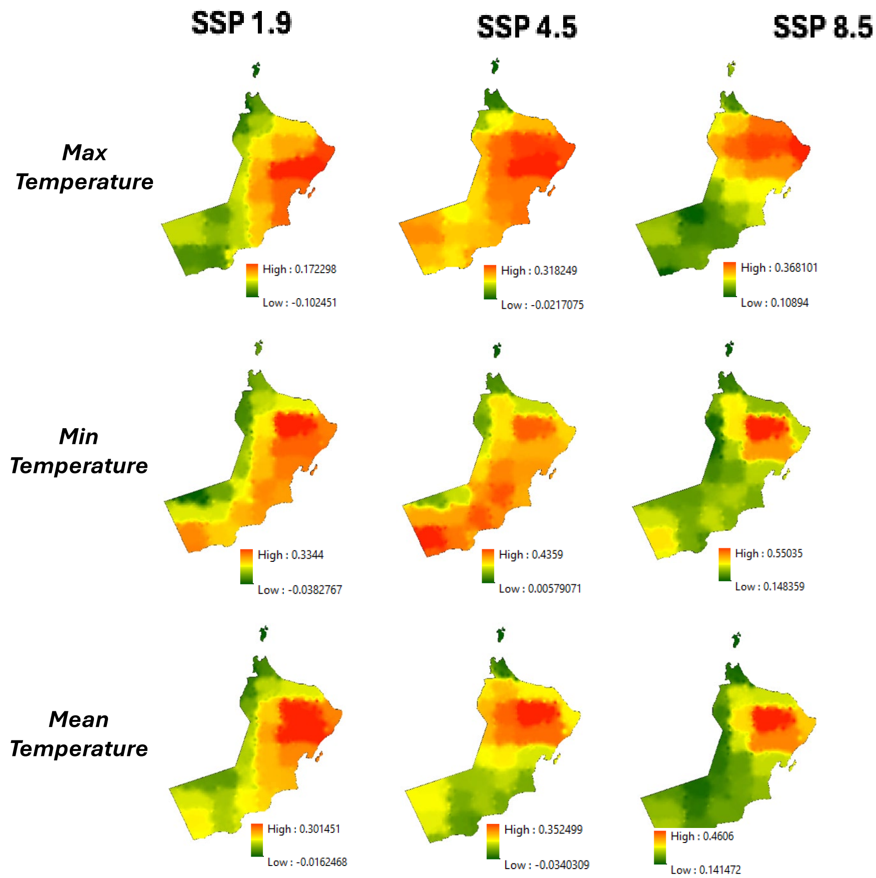


Figure 30: Anomaly assessment results for temperature variables for the early century.

These projections highlight the range of potential temperature increases in Oman, reflecting the varying impacts of different emission scenarios on regional climate.

3.1.2. First Mid-Century (2040-2059)

Moving into the first mid-century period from 2040 to 2059, the climate projections continue to show significant variations in temperature increases under the three SSP scenarios (**Figure 31**):

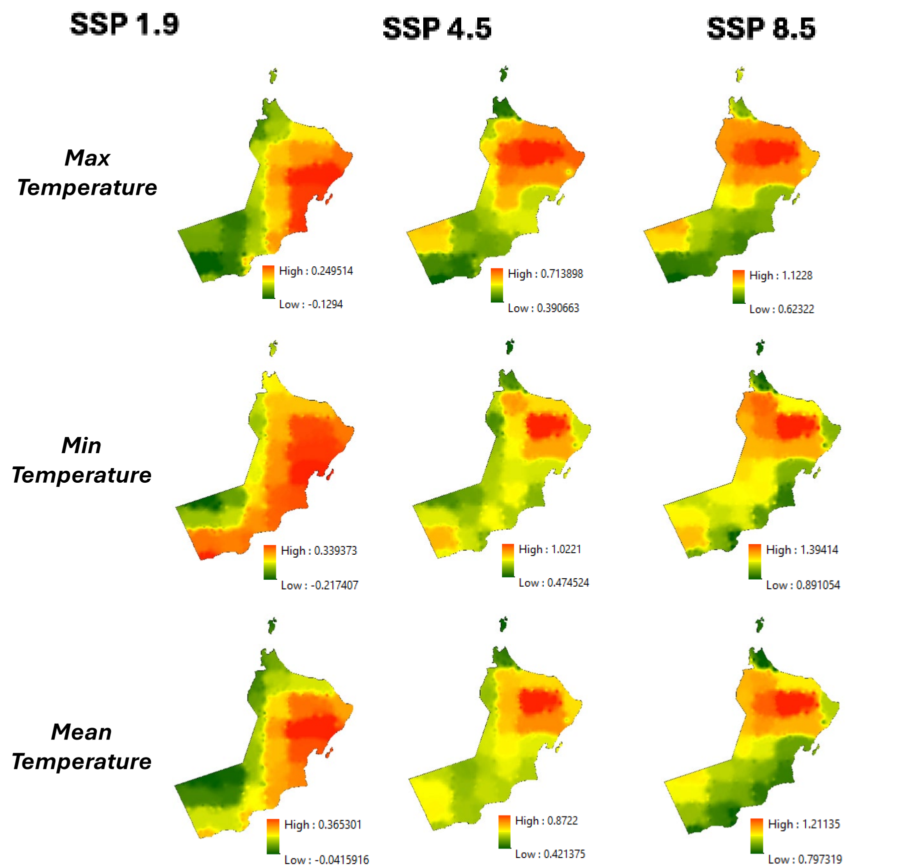


Figure 31 : Anomaly assessment results for temperature variables for the First Mid-Century.

- SSP1-1.9 (Low emissions): Mean temperatures are likely to increase by 0.4°C, especially in eastern Oman. Maximum temperatures are projected to rise by 0.3°C in eastern and northeastern areas, while minimum temperatures are expected to increase by 0.4°C in most areas.
- SSP2-4.5 (Intermediate emissions): Under this scenario, mean temperatures are expected to increase by 0.8°C in the north, but decrease by 0.4°C elsewhere. Maximum temperatures are likely to rise by 0.7°C in the north, middle, and southwest, and by 0.4°C in the east and southeast. Minimum temperatures are projected to increase by 1°C in the north and by 0.4°C elsewhere.
- SSP5-8.5 (High emissions): In this high-emissions scenario, mean temperatures are projected to increase by 1.2°C in the north and by 0.8°C in the middle and south. Maximum temperatures are expected to rise by 1.1°C in the north and southwest, and by 0.6°C in the east and southeast. Minimum temperatures are likely to increase by 1.3°C in the north and by 0.8°C elsewhere.

These mid-century projections indicate more pronounced temperature increases compared to the early century, underscoring the intensifying impacts of climate change under different emission scenarios.

3.1.3. Second Mid-Century (2060-2079)

By the late century period from 2080 to 2099, the climate projections show even greater temperature variations under the three SSP scenarios (**Figure 32**).

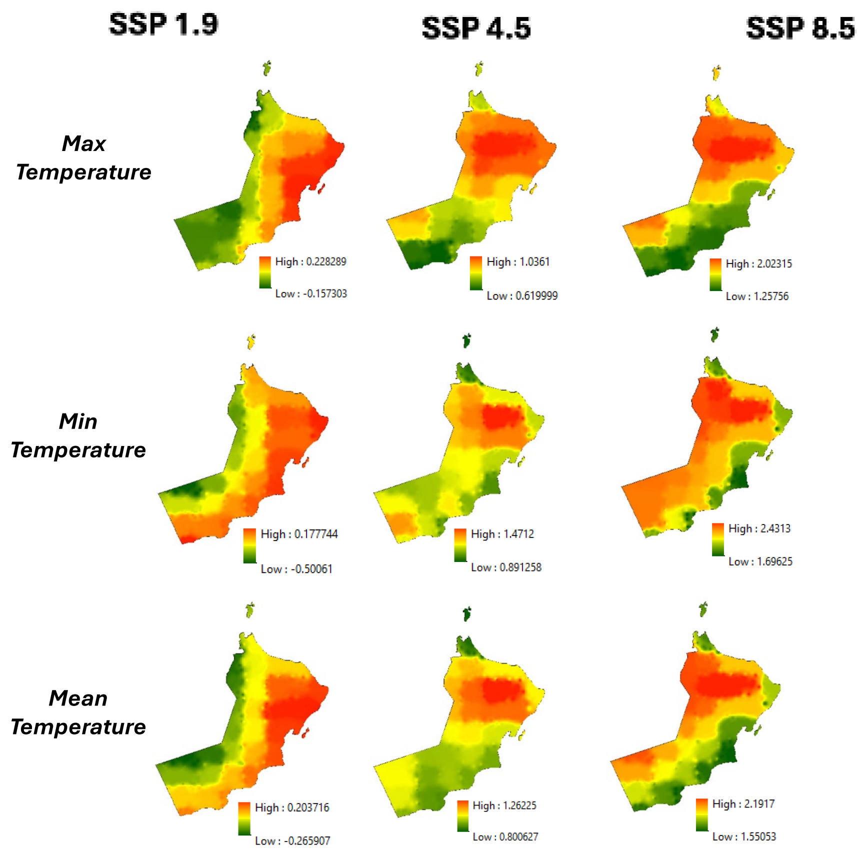


Figure 32 : Anomaly assessment results for temperature variables for the Second Mid-Century

- **SSP1-1.9 (Low emissions):** Mean and maximum temperatures are likely to increase by 0.2°C in the east and north, while decreasing by 0.1°C in the west and south. Minimum temperatures are expected to increase by 0.1°C in the east and north but decrease by 0.5°C in the west.
- **SSP2-4.5 (Intermediate emissions):** Mean temperatures are likely to increase by 1.2°C in most of the north and by 0.8°C elsewhere. Maximum temperatures are projected to increase by 1°C throughout Oman, while minimum temperatures are expected to rise by 1.4°C in the north and south, and by 0.8°C elsewhere.
- **SSP5-8.5 (High emissions):** Mean temperatures are projected to increase by 2.1°C in the northwest to southwest regions and by 1.5°C in the northeast to southeast. Maximum temperatures are expected to rise by 2°C in the north and east, and by 1.2°C in the west and south. Minimum temperatures are likely to increase by 2.4°C in some northern areas and by 1.6°C elsewhere.

These late-century projections reflect the most severe potential consequences of climate change, with significant temperature increases across all regions of Oman, emphasizing the need for robust climate action and adaptation strategies.

3.1.4. End-Century (2080-2099)

The end-century period from 2080 to 2099 presents the most significant temperature changes under different SSP scenarios (**Figure 33**).

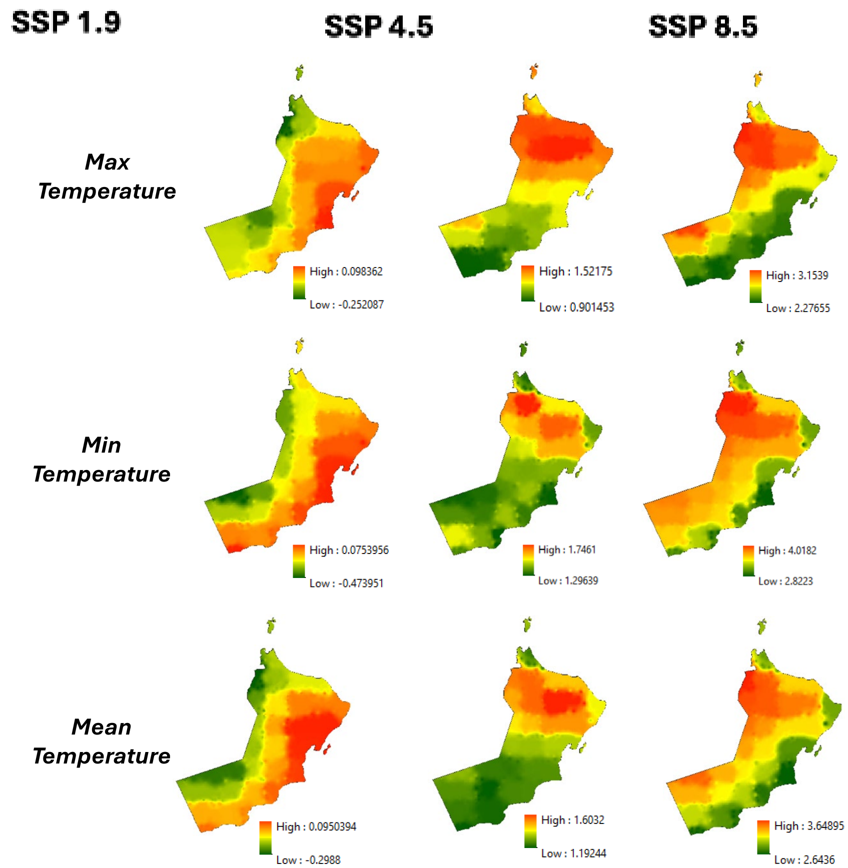


Figure 33: Anomaly assessment results for temperature variables for the End-Century.

- **SSP1-2.6 (Low emissions):** Mean and maximum temperatures are likely to increase by 0.09°C in most areas but decrease by 0.2°C in the northwest and southwest. Minimum temperatures are expected to increase by 0.07°C in most areas but decrease by 0.4°C in the northwest and southwest.
- **SSP2-4.5 (Intermediate emissions):** Mean temperatures are likely to increase by 1.6°C in the north and by 1.1°C elsewhere. Maximum temperatures are projected to increase by 1.5°C in the north and southwest, and by 0.9°C in the south. Minimum temperatures are expected to rise by 1.7°C in the north and by 1.2°C in the south.
- **SSP5-8.5 (High emissions):** Mean temperatures are projected to increase by 3.6°C in the north and northwest, and by 2.6°C elsewhere. Maximum temperatures are expected to rise by 3.5°C in the north and northwest, and by 2.2°C in the northeast. Minimum temperatures are likely to increase by 4°C in some northern areas and by 2.8°C in the northeast.

In summary, temperatures are projected to increase the most under the high-emissions SSP5-8.5 scenario, especially by the end of the century. The northern regions of Oman are likely to see the greatest warming compared to the rest of the country under most scenarios and time periods. Even under the low-emissions SSP1-2.6 scenario, slight warming is still projected in most areas by the end of the century.

3.2. Rainfall Projections

The rainfall projections for Oman indicate significant variations in precipitation patterns under different emission scenarios across various time periods:

- **Early Century (2020-2039) (Figure 34):**
    - **SSP1-1.9 (Low emissions):** Precipitation is likely to decrease by 40 mm in the northeast, leading to more drought seasons, while increasing by 49 mm elsewhere, potentially causing more rainfall and flood events.
    - **SSP2-4.5 (Intermediate emissions):** Precipitation is likely to decrease by 50 mm in the northeast, indicating more drought seasons, and increase by 59 mm elsewhere, suggesting more rainfall and flood events.
    - **SSP5-8.5 (High emissions):** Precipitation is likely to decrease by 61 mm in the northeast, resulting in more drought seasons, and increase by 70 mm elsewhere, indicating higher levels of extreme rainfall and flood events.
- **First Mid-Century (2040-2059) (Figure 34):**
    - **SSP1-1.9 (Low emissions):** Precipitation is likely to decrease by 16 mm in the northeast, causing more drought seasons, but to a lesser degree than in the early century. Precipitation is likely to increase by 28 mm elsewhere, suggesting fewer rainfall and flood events compared to the early century.
    - **SSP2-4.5 (Intermediate emissions):** Precipitation is likely to decrease by 57 mm in northeastern areas, indicating more drought seasons with a higher decrease compared to the early century. Precipitation is likely to increase by 75 mm elsewhere, suggesting more rainfall and flood events.
    - **SSP5-8.5 (High emissions):** Precipitation is likely to decrease by 57 mm in the northeast, resulting in more drought seasons but lower precipitation events compared to the early century. Precipitation is likely to increase by 44 mm elsewhere, indicating a higher level of extreme rainfall and flood events.

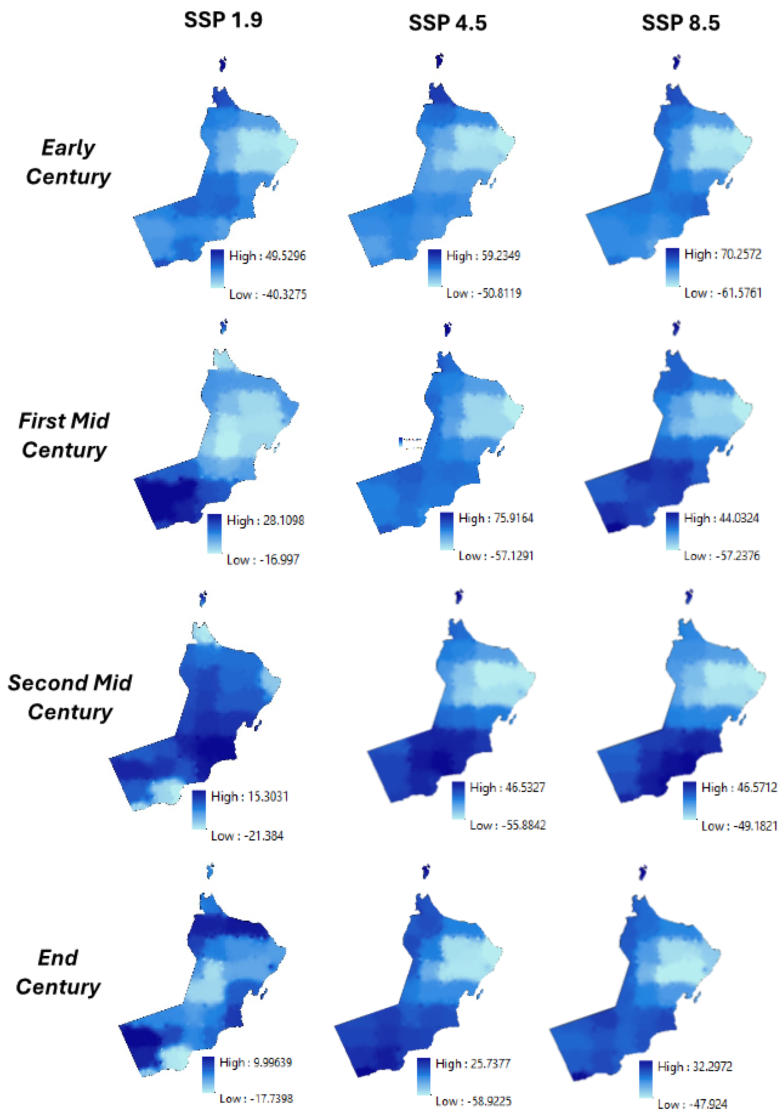


Figure 34 : Anomaly Assessment Results for Precipitation: Early, Mid, Late, and End-of-Century Periods.

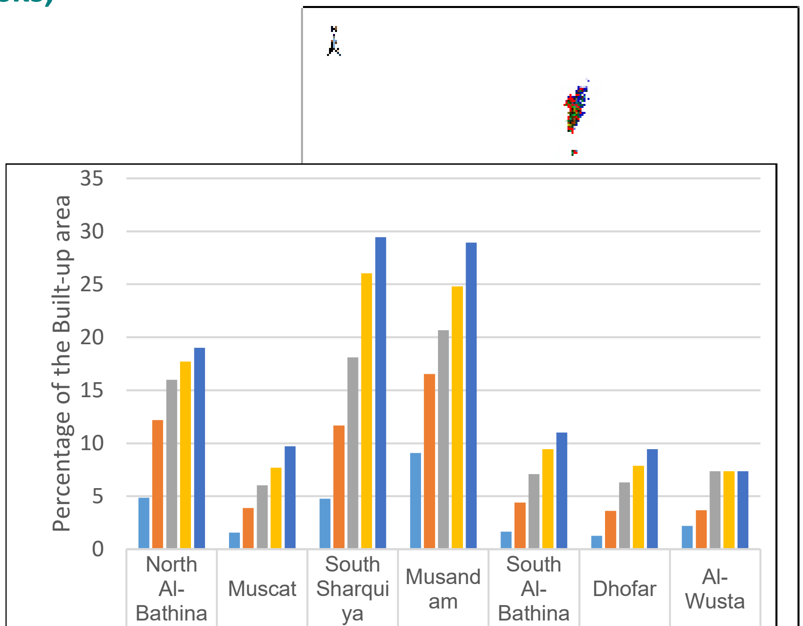
- **Second Mid-Century (2060-2079) (Figure 34):**
    - **SSP1-1.9 (Low emissions):** Precipitation is expected to increase by 15 mm in most areas and decrease by 21 mm in limited areas.
    - **SSP2-4.5 (Intermediate emissions):** Precipitation is expected to increase by 46 mm in southern Oman and decrease by 55 mm in northern Oman.
    - **SSP5-8.5 (High emissions):** Precipitation is expected to increase by 46 mm in southern Oman and decrease by 49 mm in northern Oman.
- **End-Century (2080-2099) (Figure 34)**
    - **SSP1-2.6 (Low emissions):** Precipitation is likely to increase by 9 mm in northern, southern, and mid-eastern parts of the country, while decreasing by 17 mm elsewhere, potentially reducing flood events.
    - **SSP2-4.5 (Intermediate emissions):** The highest precipitation anomalies are expected to decrease by 24 mm, lower than in the previous century, with a higher likelihood of drought in northern Oman.
    - **SSP5-8.5 (High emissions):** The highest precipitation anomalies are expected to increase by 32 mm, higher than in previous scenarios, with a decrease in precipitation of 47 mm. Total precipitation is projected to decrease compared to previous centuries under all three climate change scenarios.

In summary, precipitation patterns are projected to vary across Oman, with northeastern regions consistently likely to experience decreases in rainfall and more drought conditions under most scenarios and time periods. Other parts of Oman are projected to see increases in precipitation, particularly in the early and mid-century periods. However, by the end of the century, precipitation is generally expected to decrease compared to earlier periods under all emissions scenarios.

4. National Climate Change Risks, Impacts, and Vulnerability

4.1. Increasing Human Utilization of the Coastal Zone in Oman

Oman's population has grown significantly, from 2.8 million in 2010 to 5.1 million in 2024. Oman's diverse topography spans 309,500 square kilometers, featuring a rich variety of landscapes. The country boasts an extensive 3,165-kilometer coastline with fertile plains like Batinah in the north and Salalah in the south. Dominating the north are the Al Hajar Mountains, peaking at Jebel Shams (3,009 meters), while the Dhofar Mountains grace the south. Vast desert areas include the



	North Al-Bathina	Muscat	South Sharquiya	Musandam	South Al-Bathina	Dhofar	Al-Wusta
100 m	4.8	1.6	4.8	9.1	1.7	1.3	2.2
200m	12.2	3.9	11.7	16.5	4.4	3.6	3.7
300m	16.0	6.0	18.1	20.7	7.1	6.3	7.4
	17.7	7.7	26.0	24.8	9.4	7.9	7.4
	19.0	9.7	29.4	28.9	11.0	9.5	7.4

rcentage of Built-Up area stretched within 100m, 200m, and 500m distance from shoreline in the seven coastal of Oman.

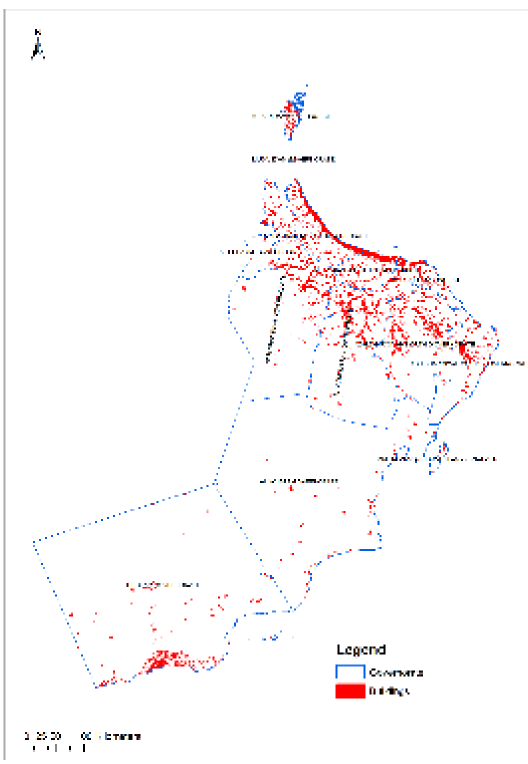


Figure 36: Spatial Distribution of Built-Up area by Governorates.

Rub' al Khali and the central gravel desert of Jiddat al-Harasis. Numerous wadis crisscross the terrain, and oases like Nizwa provide vital agricultural hubs. Over the past five decades, the utilization of Oman's coast has surged and is expected to continue increasing through the 21st century. Coastal population growth has led to the widespread transformation of natural coastal landscapes into industrial and residential areas. The coastal plains, particularly in Muscat and the Al-Bathina regions, are the primary areas of human settlement and agricultural activity (**Figure 35**). According to the 2020 census, 80% of the Omani population resides in low-lying areas such as these coastal plains, with 56.5% concentrated in Muscat and the Al-Bathina coastal plain. This plain, Oman's primary agricultural area, ranges from 0 to 500 meters in elevation and is approximately 50 kilometers wide in the middle. The Al-Batinah coastal plain has experienced rapid development over the past five decades, a trend expected to continue due to recent industrial activities.

Oman has seven coastal governorates: Musandam, North Al-Bathina, South Al-Bathina, Muscat, Al-Wusta, and Dhofar (**Figure 36**). **Figure 37,** shows the percentage of total built-up area within 100m, 200m, 300m, 400m, and 500m from the shoreline in these governorates. These figures highlight extensive and increasing urban settlement along the coastline. **Figure 38**, shows the percentage of the total built-up area within 500m of the shoreline, revealing that urban coastal settlements reach 100% in Musandam, 90% in South Al Sharquiya, and 70% in North Al-Bathinah. In South Al-Bathina, Muscat, Al-Wusta, and Dhofar, settlements range between 28% and 34%[22].

The increasing utilization of coastal zones poses significant climate change risks, including storm surges, tropical cyclones, coastal inundation, and flooding. These events threaten human settlements, infrastructure, and economic activities along the coast. Storm surges and tropical cyclones lead to severe coastal flooding, damaging homes, businesses, and critical infrastructure. Coastal inundation, driven by sea-level rise and extreme weather events, further exacerbates the vulnerability of these low-lying areas. Additionally, increased frequency and intensity of rainfall lead to flooding, disrupting daily life and economic activities. Building on ocean frontiers is hazardous, with sandy beaches signalling high-risk locations for buildings. Keeping development inland to avoid high-risk zones is crucial for natural hazard prevention, necessitating a setback line to prevent construction too close to the shore.

4.2. Urban Flooding Risk

4.2.1. Vulnerability of Omani Urban Centers

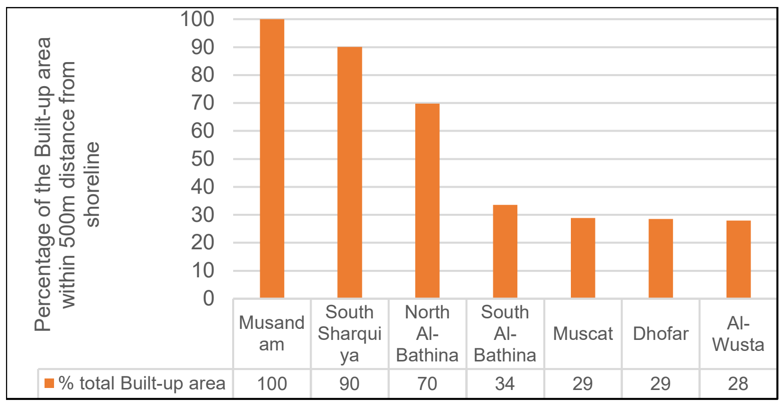


Figure 38 : Percentage from the total Built-up area stretched within 500m distance from shoreline in the seven coastal Governorates of Oman.

The Sultanate of Oman is particularly vulnerable to flash flooding due to its arid climate and unique geographical features. Historical records indicate that Oman has experienced significant flash floods in years such as 1989, 1997, 2002, 2003, 2005, 2007, 2010, 2011, 2013, and 2014, 2018 and 2021 which have caused severe damage, especially in key wadis like Wadi Aday, Wadi Kabir, and Wadi Samail. These flash floods carry large debris, including trees and boulders, leading to widespread destruction in both rural and urban areas, eventually impacting the alluvial fans and coastal regions. The settlement patterns in Oman, largely dictated by the availability of water, have resulted in many urban areas being established along wadis, making them particularly susceptible to flooding. This is especially evident in Muscat, the capital and fastest-growing city, where rapid urban expansion has led to the occupation of wadis and main channels, increasing the city's flood risk[23].

4.2.1. Contributing Factors to Flood Risks

Muscat's geographical location, surrounded by mountains, combined with its horizontal urban expansion, has exacerbated the risk of flash flooding. The literature highlights a direct correlation between urban growth and increased water runoff, a situation worsened in Oman by the lack of comprehensive sewer and drainage systems. The city's high slopes and sparse vegetation further contribute to the rapid generation of flash flood flows during heavy rainfall events. The initial flood studies in Oman, conducted in 1987 by the Council of Environment Protection & Water Resources, categorized floods into high, medium, and low hazard levels based on detailed surveys and hydraulic

[22] National Strategy for Adaptation and Mitigation to Climate Change :2020-2040 (Environment Authority).

[23] Ibid 22.

modeling. These studies were pivotal in guiding town planning and determining insurance premiums for properties against flood damage.

4.2.3. Flooding Impact Assessments

In the framework of the National Strategy for Adaptation and Mitigation to Climate Change: 2020-2040, Geographical Information System flooding risk maps were compiled, providing extensive data on the area's most vulnerable to flooding. These maps, collected from the Ministry of Agriculture, Fisheries and Water Resources, indicate that urban settlements along the coast are particularly at risk (**Annex 1**). For instance, Muscat has 16.7% of its built-up area in high flooding risk zones, translating to approximately 5,000,000 m². Similarly, Salalah and Sohar are also highly exposed, with significant portions of their built-up areas at risk of high flooding (**Figure 39**). The GIS urban environment database, developed from data collected by the National Center for Statistics and Information, further underscores the correlation between urban expansion and flood-prone areas[24].

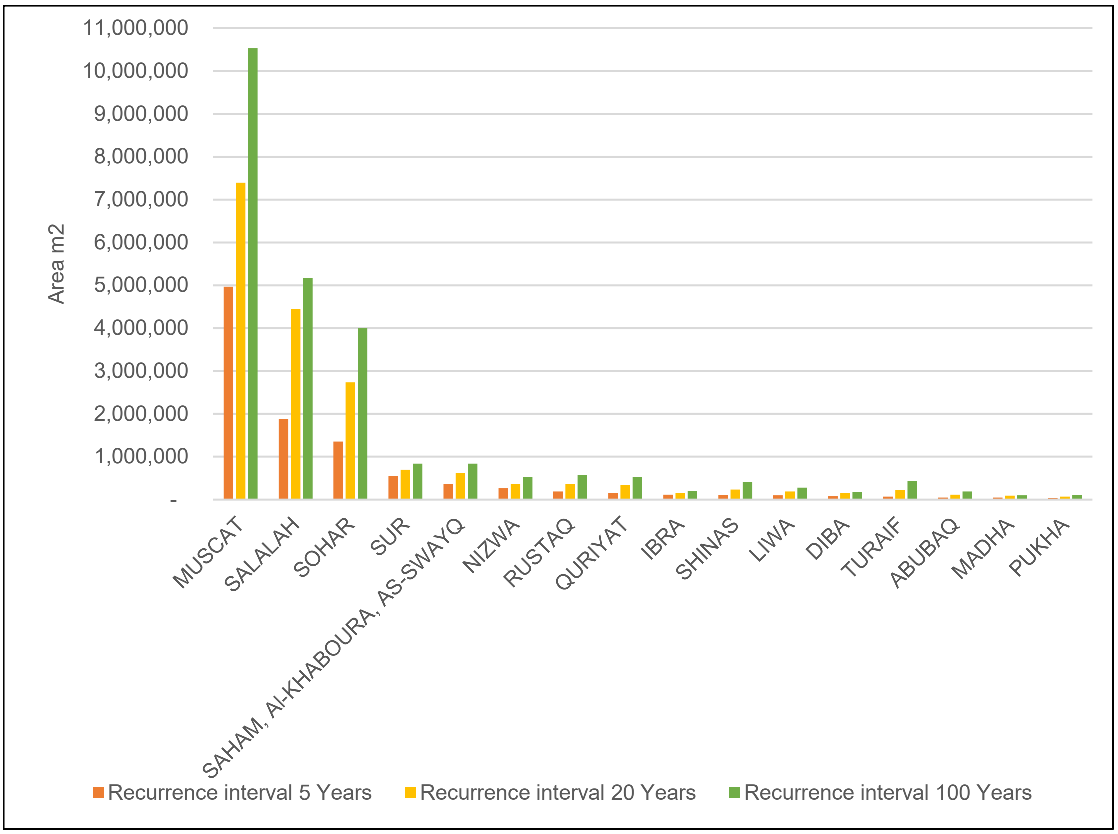


Figure 39 : High (5years recurrence), Medium (20 years recurrence) and Low (100 years recurrence) flooding risk for Built-Up area in main cities in Oman.

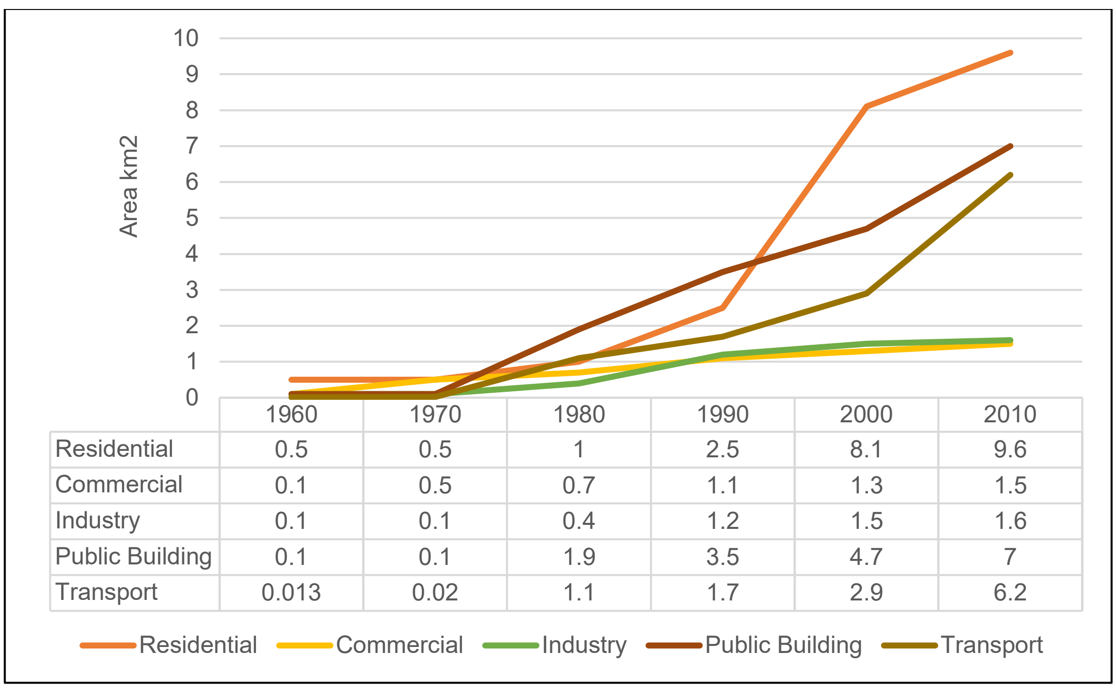
The assessment of flooding impacts in Oman also involved delineating high (5-year recurrence), medium (20-year recurrence), and low (100-year recurrence) flooding risk zones for major cities. These assessments reveal that despite the existence of flood hazard maps since 1990, urban sprawl has continued unabated in high-risk zones. Transportation infrastructure, residential areas, and public buildings have all expanded significantly within these zones, increasing the

[24] Ibid 22.

vulnerability of these urban centers to flooding. For instance, between 1990 and 2010, transportation infrastructure in high flooding risk zones in Muscat increased fivefold, residential areas fourfold, and public buildings twofold (**Figure 40**).

The National Strategy for Adaptation and Mitigation to Climate Change: 2020-2040, highlights the critical need for effective flood risk management strategies in Oman. The country's urban centers, particularly those along the coast, are inherently exposed to flooding risks due to their geographical and climatic conditions. The increasing frequency and intensity of extreme rainfall events, driven by climate change, are likely to exacerbate these risks. As the government of Oman plans significant infrastructure investments, some of which are located in flood-prone areas, there is an urgent need for adaptive measures and mitigation strategies to manage and reduce the impact of flooding. These measures are crucial to protect the population, infrastructure, and economic activities from the growing threat of flash floods. Integrating early warning systems with urban planning and emergency response can significantly enhance the resilience of Omani cities to the adverse impacts of climate change-induced flooding. An effective early warning system plays a crucial role in mitigating the impacts of flash flooding in Oman. Early warning systems provide timely and accurate information about imminent flood risks, enabling authorities and residents to take necessary precautions.

These systems help in the dissemination of alerts and warnings, coordination of emergency response, and implementation of evacuation plans. Leveraging advanced technologies and meteorological data, early warning centers can predict flash flood events and issue warnings well in advance, thereby reducing the potential loss of life and property. The integration of early warning systems with urban planning and infrastructure development is essential to enhance the resilience of Omani cities to flash flooding.



	1960	1970	1980	1990	2000	2010
Residential	0.5	0.5	1	2.5	8.1	9.6
Commercial	0.1	0.5	0.7	1.1	1.3	1.5
Industry	0.1	0.1	0.4	1.2	1.5	1.6
Public Building	0.1	0.1	1.9	3.5	4.7	7
Transport	0.013	0.02	1.1	1.7	2.9	6.2

Figure 40 : Correlation between land use patterns dynamic (1960-2010) and high flooding risk zones in Muscat.

4.3. Coastal Vulnerability to Sea Level Rise

The CVI is a widely used tool designed to guide scientists, coastal managers, and decision-makers in identifying the areas along the coastline most susceptible to the impacts of SLR and other climate change-related threats. The CVI methodology simplifies complex and interacting parameters into a manageable form, enhancing its utility as a management tool. It incorporates various physical variables such as geomorphology, coastal slope, rate of relative sea-level rise, rate of shoreline erosion/accretion, mean tide range, and mean significant wave height. Each variable is ranked, and the CVI is calculated to provide a comprehensive assessment of coastal vulnerability.

4.3.1. Quantitative Assessment of Coastal Vulnerability to Sea Level Rise

The obtained CVI values along the coastline of Oman vary between 0.32 and 8.35. The median value of the index for the entire study area is 3.81, with a standard deviation of 1.89. The spatial distribution of the vulnerability of Oman's coastline to potential sea level rise (SLR) is presented in **Figure 41**[25].

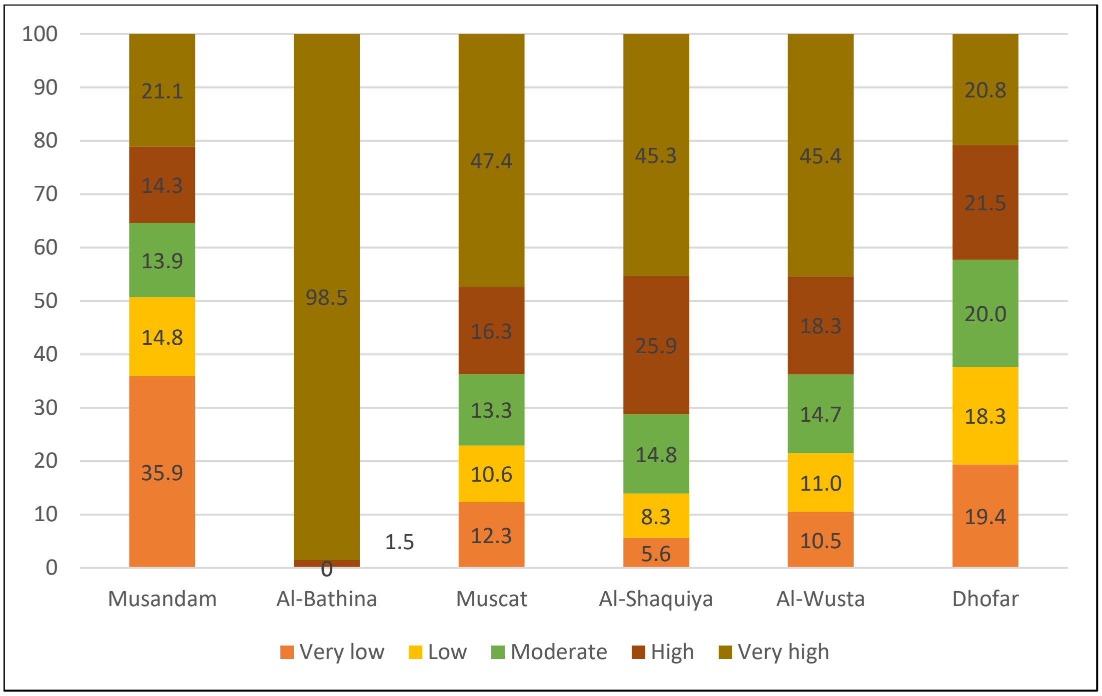


Figure 41 : CVI classes for the six coastal governorates of the Sultanate of Oman.

For the Musandam Governorate, 21.1% of the coastline is classified as very highly vulnerable to SLR. This region, bordered by the Arabian Gulf in the west, the Sea of Oman in the east, and the Strait of Hormuz in the north, features rocky, steep, and mountainous terrain. Sand beaches occur on the Arabian Gulf side, while pocket beaches are found on the eastern side, with sediments derived from nearshore sources. Numerous small wadis dissect the highly concave shoreline, creating gravel and sandy beaches.

The CVI analysis for the six coastal governorates of Oman shows that the Al Batinah coastline, located in the northeastern part of the country between the Western Hajar Mountain Range and the Sea of Oman, is the most

[25] Ibid 22.

vulnerable to SLR (98.5% very highly vulnerable). This coastline extends in a NW–SE trend for about 230 km from the UAE border to Ras al Hamra in Muscat. The Al-Batinah coast is characterized by non-indented alluvial fans and longshore sand transport along a low-lying coastal plain fringed by beaches and dunes. The plain is narrow at its northern and eastern ends, with a width of approximately 50 km in the middle. The coastal plain comprises continuous alluvial fans drained from the mountains, with sediment varying from gravel and coarse sands to fine sands and silt near the coast, suggesting a terrestrial origin for most beach sediments.

In the Muscat Governorate, 47.5% of the coastline is considered very highly vulnerable to SLR, ranking it second in terms of high vulnerability after Al Batinah. The coastline between Muscat and Ras al Hadd consists of steep cliffed coasts with wadis breaking through raised shore platforms and some small pocket beaches. The cliffed coast continues southward until it transitions to the Al Sharqiya Sands, which are predominantly flat beaches covered by beach ridges.

The Al Sharqiyah coastline is a steep cliffed coast stretching approximately 200 km along the southeastern part of the Sea of Oman, from Ras al Hamra in Muscat to Ras al Hadd. Although primarily rocky, the coastline includes indentation areas in major khawrs and embayments such as Bandar Al Khairan, Khawr Al Batih, Khawr Jaramah, and Khawr Al Hajar. Additionally, sandy and gravel beaches make up one-third of the coastline.

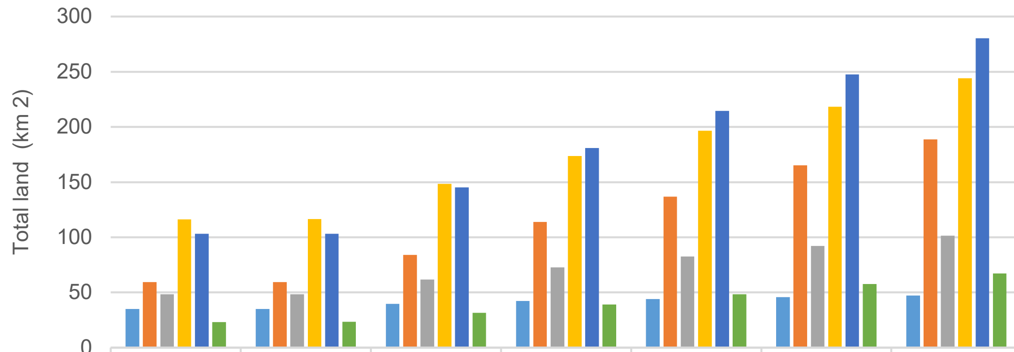
In the Al-Wusta Governorate, 45.4% of the coastline is classified as very highly vulnerable to SLR, and 18.3% as highly vulnerable. The coastline adjacent to Al Sharqiyah Sands, extending south to Barr al Hikman, is low-lying with a wide continental shelf, flat beaches, beach ridges, and sand dunes of offshore origin. The coastline between Barr al Hikman Peninsula and Ras Mudrakh is extremely flat, with sandy beaches and beach ridges caused by increasing sand deposition. Farther south, low cliffs and slightly indented sandy beaches, coral reefs, coastal sabkhas, and tidal flats are present.

For the Dhofar Governorate, the percentage of the coastline classified as very highly vulnerable to SLR is the lowest among the governorates. The Dhofar coastline extends south to the Yemen border and features high mountain cliffs with enclosed sand beaches and the relatively wide Salalah coastal plain. The Salalah coastal plain, extending approximately 50 km between Taqa and Raysut, is a low-lying sandy coast with scattered lagoons and tidal inlets supporting mangrove stands. To the east and west, steep cliffed coasts dominate the area with numerous wadi mouths.

4.3.2. Assessment of Inundation Risk from Sea Level Rise Scenarios

The results of the assessment show that Oman is highly vulnerable to climate change-induced SLR. At the national scale, nearly 400 km^2 of land area is projected to be inundated under the smallest SLR scenario, increasing to over 900 km^2 under the highest scenario (**Figure 44**). At the governorate level, the Al-Wusta Governorate in the central-south portion of the country is the most vulnerable under high SLR scenarios (i.e., greater than 2 meters), with potentially up to roughly 280 km^2 of total land inundated. The Musandam Governorate is the least vulnerable under high SLR scenarios, with under 50 km^2 of total land inundated (Figure 44). Under low SLR scenarios (i.e., less than 2 meters), the Dhofar Governorate shows the least vulnerability, with potentially up to 40 km^2 of total land inundated (**Figure 42**)[26].

[26] Ibid 22.

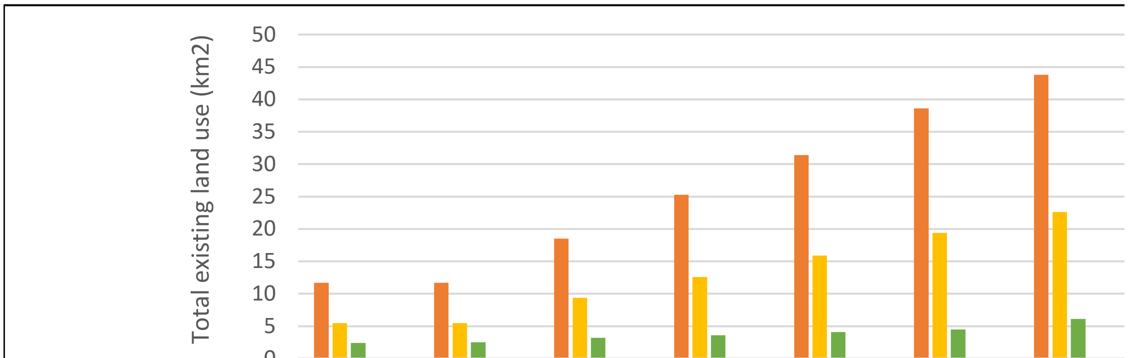


	0.2 m	0.5 m	1 m	2 m	3 m	4 m	5 m
Musandam	34.9	35.1	39.8	42.2	44.1	45.7	47.2
Al-Bathina	59.3	59.3	84	114	136.8	165.3	188.7
Muscat	48.4	48.5	61.8	72.8	82.7	92.2	101.3
Al-Sharquiya	116.1	116.5	148.4	173.6	196.4	218.3	244.1
Al-Wusta	103.1	103.3	145.3	180.8	214.6	247.6	280.3
Dhofar	23.1	23.3	31.5	39.1	48.4	57.7	67.1

Figure 42: Total inundated land area, by governorate in Oman due to projected SLR.

Currently, much of the land inundated at the governorate level is open land not under any agricultural, industrial, residential, or other use. An assessment of the vulnerability of productive land shows that the Al-Batinah and Muscat Governorates are the most vulnerable under all SLR scenarios (**Figure 43** & **Figure 44**). In Al-Batinah, where much of Oman's agricultural production occurs, rising sea levels are projected to claim between 12 km² and 44 km² of scarce arable land, corresponding to 3-4% of such land. In Muscat, the most densely populated governorate, rising sea levels are projected to claim between 5 km² and 23 km² of valuable public/private property, corresponding to 10-16% of residential, commercial, and government land.

The application of the CVI identified clusters of high vulnerability areas according to their sensitivity and dynamic nature. The governorates of Al-Bathina, Muscat, and Al-Wusta scored high due to their similar physical attributes. The concentration of major cities and industrial hubs in low-lying coastal areas suggests that Oman could face severe consequences from expected SLR, even at low rates. The vulnerability of the Omani coastal zone is likely to increase due to the continued utilization of the coastal zone, confirmed by recent developments like the new coastal city in Duqm and large investments in the industrial hub of Al-Bathina. Currently, Oman lacks a comprehensive coastal management plan to address existing problems or the consequences of SLR. Without such a plan, even low-rate sea-level rise will exacerbate issues related to coastal erosion and severe maritime intrusion in coastal aquifers. The Ministry of Housing and Urban Planning and the Environment Authority, among other authorities, have expressed concern about coastal erosion and the potential impacts of SLR on coastal communities and resources.



	0.2 m	0.5 m	1 m	2 m	3 m	4 m	5 m
Al-Bathina Land Use	11.7	11.7	18.5	25.3	31.4	38.6	43.8
Muscat Land Use	5.5	5.5	9.4	12.6	15.9	19.4	22.6
Al-Sharquiya Land Use	2.4	2.5	3.2	3.6	4.1	4.5	6.1
Musandam Land Use	0.006	0.006	0.008	0.008	0.009	0.009	0.01
Al-Wusta Land Use	0	0	0	0	0	0	0

Figure 44 : Total inundated productive land area, by governorate in Oman due to projected SLR.

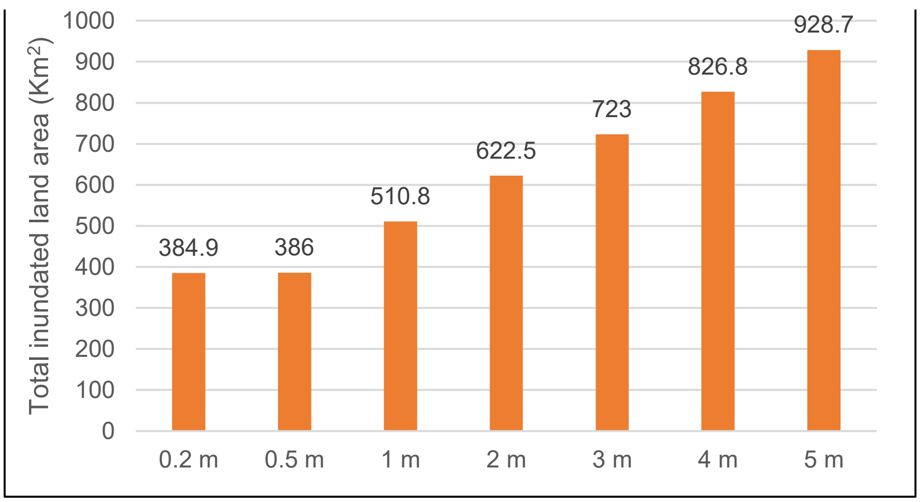


Figure 43 : Total inundated land area (Km2) in Oman due to projected SLR scenarios.

An effective coastal management plan should also incorporate the potential role of early warning centers. These centers can play a critical role in mitigating the impacts of SLR by providing timely and accurate data on sea level changes, storm surges, and other related threats. Early warning systems can facilitate prompt evacuation plans, improve emergency response, and inform infrastructure planning to reduce vulnerability. Leveraging advanced monitoring and forecasting technologies, early warning centers can enhance the resilience of coastal communities to the adverse effects of climate change and SLR. The findings of this study highlight the urgent need to develop a strategic coastal management plan that integrates early warning systems to face climate change challenges and provide a clear outlook for better adaptive resilience and responses.

4.4. Tropical Cyclones Risk

4.4.1. Severe Tropical Cyclones in Oman: A 20-Year Overview of Impacts and Damages

4.4.1.1. Tropical Cyclone ARB 01 (2002)

Tropical Cyclone ARB 01 formed on May 6, 2002, and made landfall near Salalah on May 10, 2002, before dissipating the same day (**Figure 45**)[27]. The storm caused locally heavy damage, totaling $25 million (2002 USD), and resulted in several fatalities. It brought the heaviest rainfall to Dhofar in 30 years, leading to flooding and transforming typically dry riverbeds into rivers. Several people drowned after their vehicles were swept away by the flooding, contributing to the significant local damage.

Map key

Saffir–Simpson scale

- Tropical depression (≤38 mph, ≤62 km/h)
- Tropical storm (39–73 mph, 63–118 km/h)
- Category 1 (74–95 mph, 119–153 km/h)
- Category 2 (96–110 mph, 154–177 km/h)
- Category 3 (111–129 mph, 178–208 km/h)
- Category 4 (130–156 mph, 209–251 km/h)
- Category 5 (≥157 mph, ≥252 km/h)
- Unknown

Figure 45: Tropical Cyclone ARB 01 track and intensity, according to the Saffir–Simpson scale.

[27] Track map of Tropical Cyclone ARB 01. (2002). In Wikipedia, The Free Encyclopedia. Retrieved July 21, 2024, from https://en.wikipedia.org/wiki/File: ARB 01_2002_track.png.

4.4.1.2. Tropical Cyclone Gonu (2007)

Super Cyclonic Storm Gonu was a record-breaking cyclone in the Arabian Sea during the 2007 North Indian Ocean cyclone season. It developed on June 1, 2007, rapidly intensified to peak winds of 240 km/h on June 4, and made landfall on the eastern tip of Oman early on June 6 (**Figure 46**)[28]. Gonu was the strongest cyclone to hit the Arabian Peninsula, causing severe impacts in Oman. The cyclone resulted in 50 deaths and approximately $4.5 billion in damages, making it the worst natural disaster in Oman's history. Gonu brought heavy rainfall of up to 610 mm, leading to significant flooding and widespread damage.

Map key

Saffir–Simpson scale

- Tropical depression (≤38 mph, ≤62 km/h)
- Tropical storm (39–73 mph, 63–118 km/h)
- Category 1 (74–95 mph, 119–153 km/h)
- Category 2 (96–110 mph, 154–177 km/h)
- Category 3 (111–129 mph, 178–208 km/h)
- Category 4 (130–156 mph, 209–251 km/h)
- Category 5 (≥157 mph, ≥252 km/h)
- Unknown

Figure 46: Tropical Cyclone Gonu track and intensity, according to the Saffir–Simpson scale.

[28] Track map of Super Cyclonic Storm Gonu. (2007). In Wikipedia, The Free Encyclopedia. Retrieved July 21, 2024, from https://en.wikipedia.org/wiki/File:Gonu_2007_track.png.

4.4.1.3. Tropical Cyclone Phet (2010)

Very Severe Cyclonic Storm Phet was a powerful tropical cyclone that made landfall in Oman, western India, and Pakistan (**Figure 47**)[29]. It was the third named cyclone of the 2010 cyclone season, developing in the Arabian Sea on May 31 to the west of India. Benefiting from conducive environmental conditions, Phet intensified to peak sustained winds of 155 km/h (95 mph) on June 2, as per the India Meteorological Department. The cyclone brought heavy rainfall across eastern Oman on June 3, with Qurayyat receiving a peak of 603 mm (23.7 inches). This rainfall led to severe flooding, and caused significant damage to thousands of homes. The storm resulted in 24 fatalities and an estimated $780 million in damages in Oman. After moving past Oman on June 4, Phet turned northeast, affecting Pakistan and India before dissipating on June 7, 2010.

.

Map key

Saffir–Simpson scale

- Tropical depression (≤38 mph, ≤62 km/h)
- Tropical storm (39–73 mph, 63–118 km/h)
- Category 1 (74–95 mph, 119–153 km/h)
- Category 2 (96–110 mph, 154–177 km/h)
- Category 3 (111–129 mph, 178–208 km/h)
- Category 4 (130–156 mph, 209–251 km/h)
- Category 5 (≥157 mph, ≥252 km/h)
- Unknown

Figure 47: Tropical Cyclone Phet track and intensity, according to the Saffir–Simpson scale.

4.4.1.4. Tropical Cyclone Chapala (2015)

[29] Track map of Very Severe Cyclonic Storm Phet. (2010). In Wikipedia, The Free Encyclopedia. Retrieved July 21, 2024, from https://en.wikipedia.org/wiki/File:Phet_2010_track.png.

Extremely Severe Cyclonic Storm Chapala struck Somalia, Yemen, and the southern coast of Oman in November 2015, causing moderate damage. It formed on October 28, 2015, and dissipated on November 4, 2015. Chapala reached peak winds of 215 km/h (135 mph) according to the IMD and 240 km/h (150 mph) according to the JTWC, making it one of the strongest cyclones in the Arabian Sea (**Figure 48**)[30].

Chapala made landfall near Mukalla, Yemen, and affected the southern coast of Oman on November 3, 2015, as the strongest storm on record to hit the region, leading to widespread evacuations. The cyclone resulted in eight fatalities and 65 injuries in Yemen, with significant infrastructure damage due to heavy rainfall and flooding. Somalia experienced the destruction of 350 houses and the loss of tens of thousands of animals. The southern coast of Oman experienced widespread flooding and damage to property and infrastructure, although the damage cost was not reported.

Map key

Saffir–Simpson scale

- Tropical depression (≤38 mph, ≤62 km/h)
- Tropical storm (39–73 mph, 63–118 km/h)
- Category 1 (74–95 mph, 119–153 km/h)
- Category 2 (96–110 mph, 154–177 km/h)
- Category 3 (111–129 mph, 178–208 km/h)
- Category 4 (130–156 mph, 209–251 km/h)
- Category 5 (≥157 mph, ≥252 km/h)
- Unknown

Figure 48: Tropical Cyclone Chapala track and intensity, according to the Saffir–Simpson scale.

[30] Track map of Extremely Severe Cyclonic Storm Chapala. (2015). In Wikipedia, The Free Encyclopedia. Retrieved July 21, 2024, from https://en.wikipedia.org/wiki/File:Chapala_2015_track.png.

4.4.1.5. Tropical Cyclone Mekunu (2018)

Extremely Severe Cyclonic Storm Mekunu was the strongest storm to strike Oman's Dhofar Governorate since 1959. The second named storm of the 2018 North Indian Ocean cyclone season, Mekunu developed from a low-pressure area on May 21. It gradually intensified, passing east of Socotra on May 23 as a very intense tropical cyclone. Mekunu reached its peak intensity on May 25, with the India Meteorological Department estimating 10-minute sustained winds of 175 km/h (110 mph), classifying it as an extremely severe cyclonic storm. The Joint Typhoon Warning Center estimated slightly higher 1-minute winds of 185 km/h (115 mph). At peak intensity, Mekunu made landfall near Raysut, Oman, on May 25 and rapidly weakened over land, dissipating on May 27 (**Figure 49**)[31]. While passing near Socotra, Cyclone Mekunu dropped heavy rainfall, causing landslides and flooding. In Oman, Mekunu killed 30 and caused about $1.5 billion in damage. Rainfall from Mekunu reached 617 mm (24.3 inches) in Salalah, creating desert lakes in the Empty Quarter (Rub' al Khali) and contributing to a locust outbreak.

Map key

Saffir–Simpson scale

- Tropical depression (≤38 mph, ≤62 km/h)
- Tropical storm (39–73 mph, 63–118 km/h)
- Category 1 (74–95 mph, 119–153 km/h)
- Category 2 (96–110 mph, 154–177 km/h)
- Category 3 (111–129 mph, 178–208 km/h)
- Category 4 (130–156 mph, 209–251 km/h)
- Category 5 (≥157 mph, ≥252 km/h)
- Unknown

Figure 49: Tropical Cyclone Mekunu track and intensity, according to the Saffir–Simpson scale.

[31] Track map of Extremely Severe Cyclonic Storm Mekunu. (2018). In Wikipedia, The Free Encyclopedia. Retrieved July 21, 2024, from https://en.wikipedia.org/wiki/File:Mekunu_2018_track.png.

4.4.1.6. Tropical Cyclone Luban (2018)

Very Severe Cyclonic Storm Luban was the third tropical cyclone to affect the Arabian Peninsula during the 2018 North Indian Ocean cyclone season, following cyclones Sagar and Mekunu in May. Luban developed on October 6 in the central Arabian Sea and maintained a west-northwestward trajectory for most of its duration. On October 10, the India Meteorological Department (IMD) upgraded Luban to a very severe cyclonic storm, equivalent to a Category 1 hurricane, with maximum sustained winds of 140 km/h (85 mph). The storm made landfall in eastern Yemen on October 14 as a cyclonic storm and quickly weakened over the dry, mountainous terrain of the Arabian Peninsula, dissipating on October 15 (**Figure 50**)[32].

Cyclone Luban caused significant flooding rains in Somalia, Oman, and Yemen. In Yemen, the heavy rainfall cut off villages, damaged roads, and resulted in 14 fatalities. The damage in Yemen was estimated at $1 billion. In Oman, Luban caused flooding and damage to property and infrastructure, although the cost of the damage was not reported by Omani officials. Desert rainfall in Oman also led to a small locust outbreak. Luban coexisted with Very Severe Cyclonic Storm Titli in the Bay of Bengal, marking the first time since 1971 that two storms of such intensity were active simultaneously in the North Indian Ocean.

Map key

Saffir–Simpson scale

- Tropical depression (≤38 mph, ≤62 km/h)
- Tropical storm (39–73 mph, 63–118 km/h)
- Category 1 (74–95 mph, 119–153 km/h)
- Category 2 (96–110 mph, 154–177 km/h)
- Category 3 (111–129 mph, 178–208 km/h)
- Category 4 (130–156 mph, 209–251 km/h)
- Category 5 (≥157 mph, ≥252 km/h)
- Unknown

Figure 50: Tropical Cyclone Luban track and intensity, according to the Saffir–Simpson scale.

[32] Track map of Very Severe Cyclonic Storm Luban. (2018). In Wikipedia, The Free Encyclopedia. Retrieved July 21, 2024, from https://en.wikipedia.org/wiki/File:Luban_2018_track.png.

4.4.1.7. Tropical Cyclone Hikaa (2019)

Very Severe Cyclonic Storm Hikaa struck eastern Oman in September 2019. Forming on September 22, 2019, west of India in the Arabian Sea, Hikaa reached its peak intensity on September 24 with maximum sustained winds estimated at over 140 km/h (85 mph). The storm made landfall in eastern Oman, south of Duqm, later that day and quickly dissipated over the Arabian Peninsula by September 25, 2019 (**Figure 51**)[33]. The cyclone resulted in significant damage to infrastructure in the affected regions.

Map key

Saffir–Simpson scale

- Tropical depression (≤38 mph, ≤62 km/h)
- Tropical storm (39–73 mph, 63–118 km/h)
- Category 1 (74–95 mph, 119–153 km/h)
- Category 2 (96–110 mph, 154–177 km/h)
- Category 3 (111–129 mph, 178–208 km/h)
- Category 4 (130–156 mph, 209–251 km/h)
- Category 5 (≥157 mph, ≥252 km/h)
- Unknown

Figure 51: Tropical Cyclone Hikaa track and intensity, according to the Saffir–Simpson scale.

[33] Track map of Very Severe Cyclonic Storm Hikaa. (2019). In Wikipedia, The Free Encyclopedia. Retrieved July 21, 2024, from https://en.wikipedia.org/wiki/File:Hikaa_2019_track.png.

4.4.1.8. Tropical Cyclone Shaheen (2021)

Severe Cyclonic Storm Shaheen, initially forming as Cyclonic Storm Gulab on September 24, 2021, made landfall in Oman on October 3, 2021, and dissipated on October 4, 2021 (**Figure 52**)[34]. The cyclone caused extensive water-related damage, particularly in Muscat, where heavy rainfall and flooding submerged cars and other low-lying objects. Shaheen disrupted communications and caused significant infrastructure damage across the northeastern governorates. Oman allocated $500 million in its 2022 budget to repair the damages caused by Cyclone Shaheen.

Map key

Saffir–Simpson scale

- Tropical depression (≤38 mph, ≤62 km/h)
- Tropical storm (39–73 mph, 63–118 km/h)
- Category 1 (74–95 mph, 119–153 km/h)
- Category 2 (96–110 mph, 154–177 km/h)
- Category 3 (111–129 mph, 178–208 km/h)
- Category 4 (130–156 mph, 209–251 km/h)
- Category 5 (≥157 mph, ≥252 km/h)
- Unknown

Figure 52: Tropical Cyclone Shaheen track and intensity, according to the Saffir–Simpson scale.

4.4.2. Oman's Rising Tropical Cyclone Threat: Historical Insights and Future Storm Surge Projections

Coastal flooding associated with tropical cyclones has become a major concern in low-lying populated areas in Oman. Cyclone Gonu in 2007, which led to 50 deaths in Oman and over $4.5 billion in property damage, highlighted the need for preparedness against such extreme weather events. The vulnerability of Oman's infrastructure to tropical cyclones was evaluated through an analysis of the historical cyclones (DGM, 2015).

The long-term wave and surge maximum potential storm surge depth associated with reanalysis for the marine climate was based on the Global Ocean Wave reanalysis database and the Climate Forecast System Reanalysis wind and sea level pressure database. This provided high-resolution information on the regional wave and storm surge along the Omani coast. Developing an understanding of the historical frequency and intensity of tropical cyclones was based on the synthetic generation of hypothetical and plausible tropical cyclones using state-of-the-art trajectory stochastic models. It also involved data collection and review of historical tropical cyclone tracks in recent years, including events such as Gonu and Phet.

[34] Track map of Cyclonic Storm Gulab/Severe Cyclonic Storm Shaheen. (2021). In Wikipedia, The Free Encyclopedia. Retrieved July 21, 2024, from https://en.wikipedia.org/wiki/File:Gulab-Shaheen_2021_track.png

The extent of coastal flooding was simulated using a high-resolution numerical hydrodynamic model to evaluate the storm surge associated with each cyclone event. Modeling assumed historical mean sea levels under the influence of astronomical tides, providing a lower estimate of potential storm surge associated with tropical cyclones under climate change.

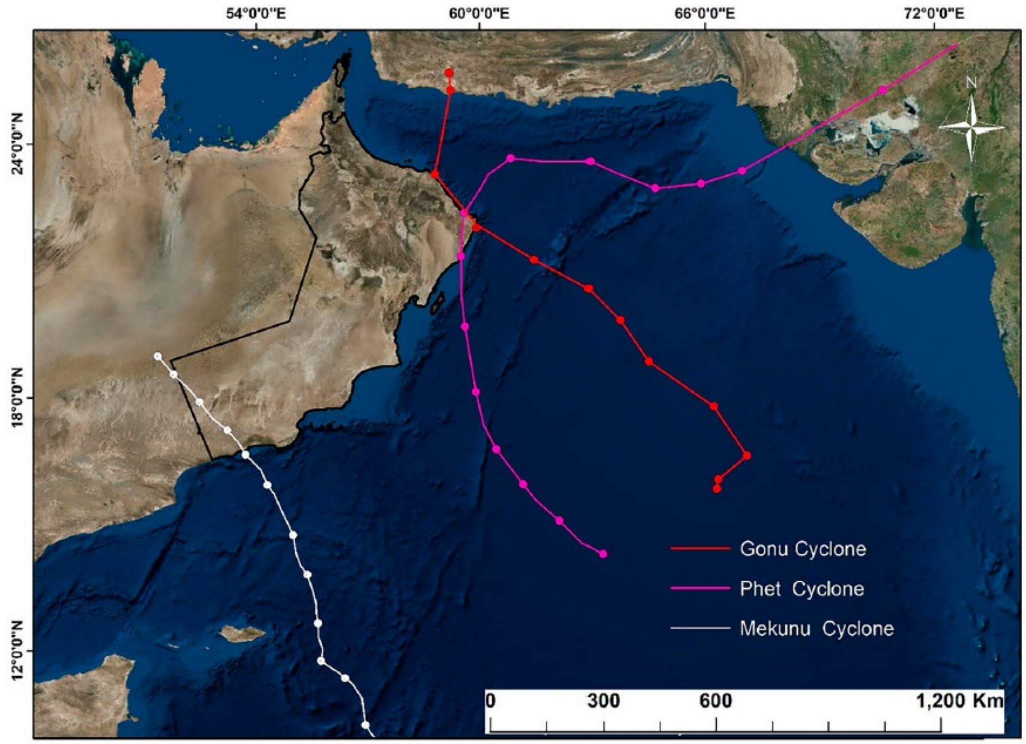


Figure 53: Highest-impact cyclone tracks.

From over 800 tropical cyclone paths that have entered the Arabian Sea, three were identified as having the potential for maximum impact on infrastructure in Oman (

Figure 53). The minimum storm surge from the analysis of all potential cyclone tracks is between 3 and 4 meters high. Maximum storm surge height reaches nearly 6 meters in parts of the Al Wusta governorate, with South Al Sharquiya also being highly exposed to storm surges between 4.5 and 5.0 meters (**Figure 54**). Any infrastructure located along the coastline where the highest storm surge is projected is clearly at high risk during future cyclonic events (**Annex 2**).

The growing frequency and intensity of tropical cyclones pose a significant threat to Oman's coastal regions. The innovative simulation methodology developed by Oman's Meteorological Department represents a crucial step forward in understanding and preparing for the potential impacts of tropical cyclones and associated storm surges. Regularly updating data and models is essential for refining risk assessments and ensuring effective emergency response strategies. Enhancing the capacity of the Early Warning Center is imperative to ensure timely and accurate dissemination of information to vulnerable communities and decision-makers, including investment in technology, training, and resources to provide actionable insights and guidance in real-time.

4.5. High-Temperature Stress in Oman: Health, Crop Productivity, and

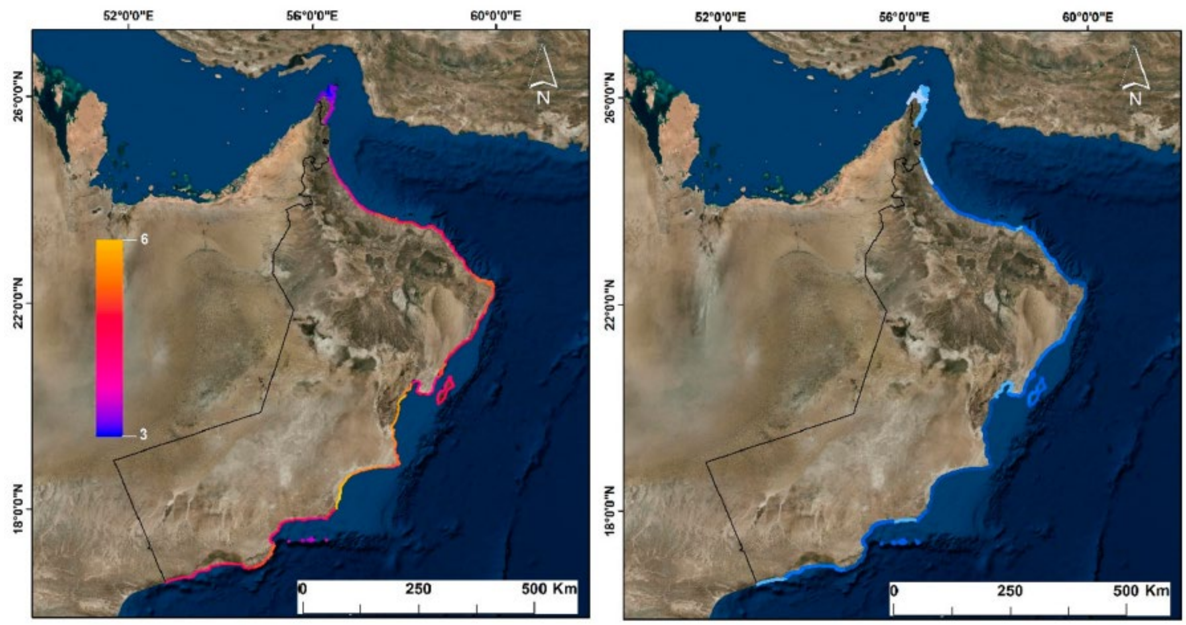


Figure 54: Minimum (Left) and Maximum (Right) Projected Storm Surge Heights from Assessment of All Potential Tropical Cyclone Tracks.

Infrastructure Risks

The AR6 report by the IPCC provides a detailed overview of the current scientific understanding of climate change and its impacts on various regions worldwide, including Oman. The report highlights that the Arabian Peninsula, particularly Oman, is expected to experience significant warming, with temperature increases projected to be among the highest globally. This warming is expected to be accompanied by reduced rainfall, increased frequency and intensity of heat waves and dust storms, and heightened vulnerability to sea-level rise and coastal flooding due to the high population density in low-lying coastal areas. The Key Projections from the AR6 Report are as follows:

- **Temperature Increases:** Under the Shared Socioeconomic Pathways (SSP5-8.5) scenario, Oman could see a daily maximum temperature anomaly of +6.5°C by 2100. This could result in peak temperatures reaching 52.06°C in the interior Governorate of Al Dhahira (**Figure 55**).
- **Hot Days Expansion:** The number of hot days (Tmax > 45°C) is projected to increase across all governorates. For example, Adahira could experience an increase of 110.65 hot days per year under the SSP5-8.5 scenario, while Adkhilia might see 79.62 more hot days, Asharquia 30.72, and Dhofar 22.87 more hot days annually (**Figure 56**).

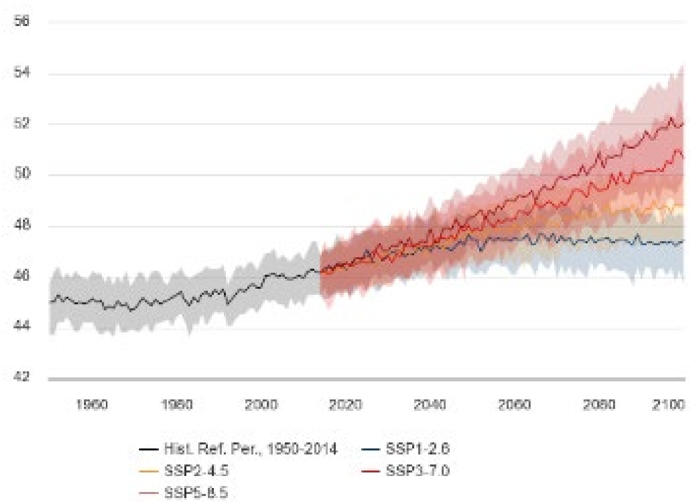


Figure 55: Projected Maximum of Daily Max-Temperature (Tc) for the governorate of Al Dhahira from 2014 to 2100, based on the IPCC's future climate scenarios (SSP1-1.9; SSP1-2.6; SSP2-4.5; SSP3-7.0 and SSP5-8.5).

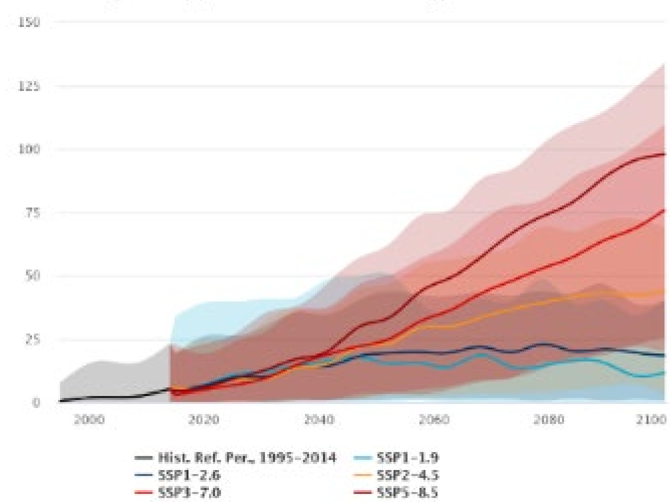


Figure 56: Projected Number of Hot Days (Tmax >45 C) for the governorate of Al Dhahira from 2014 to 2100, based on the IPCC's future climate scenarios (SSP1-1.9; SSP1-2.6; SSP2-4.5; SSP3-7.0 and SSP5-8.5).

4.5.1. Public Health Risks

These extreme temperature increases pose severe health risks, particularly for vulnerable populations such as the elderly, children, and individuals with pre-existing health conditions. Prolonged exposure to high temperatures can lead to heat exhaustion, heatstroke, and exacerbate chronic health conditions. Additionally, the number of working days' outdoors will be reduced, impacting labor productivity and economic activities reliant on outdoor work. The hot weather in Oman significantly impacts construction projects, necessitating comprehensive modeling, investigation, and quantification to mitigate adverse effects, particularly on workers' health. The construction industry in Oman, characterized by high temperatures and humidity, faces substantial productivity challenges due to weather conditions. Severe heat can lead to project delays, cost overruns, and decreased labor productivity.

A study that developed a construction productivity model using NIOSH's work/rest schedule revealed that hot and humid weather could extend project durations by 3-38% longer than planned. The physiological impacts of heat stress on workers, including increased occupational injuries and fatalities, are profound. There is a notable rise in accidents between 11:00 and 17:00 due to excessive heat[35]. This is further corroborated by research indicating that the majority

[35] Mubarak, Khamis, Al, Alawi. (2020). Modeling, Investigating, and Quantification of the Hot Weather Effects on Construction Projects in Oman. The Journal of Engineering Research, 17(2):89-99.

of construction workers in Oman are overweight or hypertensive, exacerbating the risks associated with heat stress. The adverse effects of hot weather on construction projects are not limited to physical health and material integrity but also extend to project timelines and financial outcomes. Delays in construction projects, often exacerbated by unforeseen weather conditions, can lead to significant financial losses and strained relationships among stakeholders[36].

4.5.2. Crop Productivity Risks

Elevated temperatures due to climate change are anticipated to have a significant impact on Oman's agricultural sector, particularly on the cultivation of palm trees, which play a crucial role in the country's heritage and economy. The key concerns from high temperature stress are as follows:

- **Palm Tree Cultivation:** Date palms, a staple crop in Oman, are highly susceptible to heat stress. Rising temperatures and changing precipitation patterns can negatively impact their growth and productivity. Heat waves, characterized by prolonged periods of excessively high temperatures, have significant impacts on palm trees, similar to other tree species. The physiological stress induced by heat waves can lead to a reduction in photosynthetic capacity, increased photooxidative stress, and potential leaf abscission, which collectively impair the growth and health of palm trees. Heat stress can overall decrease growth and alter biomass allocation in palm trees. When accompanied by drought, the negative effects of heat stress are exacerbated, potentially leading to tree mortality[37].
- **Water Stress:** Increased temperatures can disrupt the balance of water availability, leading to water stress in palm trees. Irregular rainfall patterns can further exacerbate this stress by affecting irrigation practices. Heat waves, characterized by prolonged periods of excessively high temperatures, significantly exacerbate water stress across various ecosystems, impacting plants, animals, and humans alike. In plants, heat waves combined with water stress can lead to severe physiological disruptions, including reduced photosynthesis, impaired respiration, and decreased growth and reproductive success[38].
- **Pest and Disease Proliferation:** Heat waves, characterized by prolonged periods of abnormally high temperatures, have significant impacts on pest and disease proliferation in crops, exacerbating challenges in agricultural productivity. The increased frequency and intensity of heat waves due to climate change have been shown to affect various biological processes in plants and pests. For instance, heat stress in plants can lead to structural changes, enzyme function disruption, and oxidative damage, which can weaken plant defenses and make them more susceptible to pests and diseases[39]. Studies on tritrophic food webs, such as those involving Capsicum anuum, aphids, and parasitoids, indicate that heat waves can alter the osmolarity of plant sap, suggesting increased stress compounds that may affect herbivore performance and interspecies interactions[40].
- **Socio-Economic Consequences:** Heat waves, exacerbated by climate change, have profound impacts on agricultural productivity and, consequently, farmer incomes globally, including in regions like Oman. The increasing frequency and intensity of heat waves lead to significant agricultural losses, as evidenced by global data showing that past heat waves have caused agricultural losses up to ten times larger than previously estimated by standard approaches[41]. In Oman, similar to other regions, heat waves can severely affect crop yields, particularly during critical growth stages, leading to reduced harvests and lower incomes for farmers. For instance, in India, heat waves during the grain filling stage of wheat resulted in a 15-25% yield

[36] Tariq, Umar., Charles, Egbu. (2020). Heat stress, a hidden cause of accidents in construction. doi: 10.1680/JMUEN.18.00004

[37] Robert, O., Teskey., Timothy, M., Wertin., Ingvar, Bauweraerts., Maarten, Ameye., Mary, Anne, McGuire., Kathy, Steppe. (2015). Responses of tree species to heat waves and extreme heat events. Plant Cell and Environment, doi: 10.1111/PCE.12417.

[38] Michael, Davies., Heath, Ecroyd., Sharon, A., Robinson., Kristine, French. (2018). Stress in native grasses under ecologically relevant heat waves. PLOS ONE, doi: 10.1371/JOURNAL.PONE.0204906.

[39] Vanitha, Sampath., Omar, Shalakhti., Erika, M, Veidis., Jo, Ann, Ifeoma, Efobi., Mohamed, H., Shamji., Ioana, Agache., Chrysanthi, Skevaki., Harald, Renz., Kari, C., Nadeau. (2023). Acute and Chronic Impacts of Heat Stress on Planetary Health. Allergy, doi: 10.1111/all.15702.

[40] David, R., Gillespie., Abida, Nasreen., Chandra, E., Moffat., Peggy, Clarke., Bernard, D., Roitberg. (2012). Effects of simulated heat waves on an experimental community of pepper plants, green peach aphids and two parasitoid species. Oikos, doi: 10.1111/J.1600-0706.2011.19512.X.

[41] Steve, Miller., Kenn, Chua., Jay, S., Coggins., Hamid, Mohtadi. (2021). Heat Waves, Climate Change, and Economic Output. Journal of the European Economic Association, doi: 10.1093/JEEA/JVAB009.

reduction[42] [1]. This pattern is likely to be mirrored in Oman, where high temperatures can cause crops to mature prematurely, reducing both the quantity and quality of produce. Additionally, heat waves contribute to water scarcity, a critical issue in arid regions like Oman, further stressing agricultural systems and reducing productivity.

4.5.3. Infrastructure Risks

High temperatures also pose significant risks to essential infrastructure in Oman, including roads, buildings, and the electric sector. The Key Implications for infrastructure from the high temperature risk are as follows:

- **Infrastructure Deterioration:** Increased heat accelerates the deterioration of roads and structures, compromising transportation networks and daily life. The durability of asphalt and concrete pavements is significantly impacted by hot climates, which exacerbate various forms of deterioration. High temperatures accelerate the evaporation of moisture from concrete, leading to rapid hardening and increased cracking potential, which compromises both fresh and hardened concrete properties. In hot and desert areas, where temperatures can reach 40 to 50°C, the rapid loss of mixing water by evaporation further deteriorates the concrete's structural integrity, affecting its workability and compressive strength[43]. The strength of pavement decreases significantly with rising temperatures, as observed in a study where pavement strength dropped from 3330 Megapascals at 30°C to 423 MPA at 70°C[44]. This can lead to higher maintenance costs and increased disruption to daily activities.
- **Electric Sector Challenges:** Oman's electric sector, which relies heavily on fossil fuels, faces challenges as rising temperatures increase energy demand for cooling. This can strain energy resources and contribute to higher greenhouse gas emissions, creating a feedback loop that exacerbates climate change. The hot climate significantly impacts the electric grid and power stations, posing various challenges and necessitating adaptive measures to ensure reliability and efficiency. High temperatures and more frequent heat waves can degrade the operational lifetime of critical components like large power transformers (LPTs), increasing the risk of premature failure and prolonged grid disruptions, as observed in the Northeast United States[45]. The increased frequency and intensity of extreme weather events, such as heat waves, storms, and wildfires, further exacerbate the vulnerability of the electric grid, leading to more frequent and severe power outages. The electric grid, originally designed for past climate conditions, is now exposed to more extreme conditions, leading to potential operational failures as it may not function as intended under these new stresses[46]. For instance, extreme weather events, including heat waves, have been the leading cause of significant power outages, with a notable increase in the duration of such outages in the U.S. between 2000 and 2012[47]. Additionally, the increased frequency and intensity of hot days can accelerate the deterioration of grid components, necessitating higher capital and maintenance expenditures and potentially leading to increased power prices for consumers

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[42] Divya, Singh., Atish, K, Yadav., Shubhendu, Kunwar, Singh., Mrinal, Sen., Amrendra, K., Yadav., Ashok, K., Mishra., Anil, Kumar, Singh. (2023). Heat Waves and Its Impact on Crop Production and Mitigation Techniques: A Review. International Journal of Enviornment and Climate Change, doi: 10.9734/ijecc/2023/v13i92243.

[43] Rawan, Farhan, Ramadan., Hassan, Ghanem., Jamal, Khatib., Adel, Elkordi. (2022). Effect of hot weather concreting on the mechanical and durability properties of concrete-a review. doi: 10.54729/axec5733.

[44] I.Sh., Sadikov., Farrukh, Ashurov. (2023). Determining the minimum speed of trucks on automobile roads in hot climate. Nucleation and Atmospheric Aerosols, doi: 10.1063/5.0113034.

[45] Xiang, Gao., C., Adam, Schlosser., Eric, R., Morgan. (2018). Potential impacts of climate warming and increased summer heat stress on the electric grid: a case study for a large power transformer (LPT) in the Northeast United States. Climatic Change, doi: 10.1007/S10584-017-2114-X.

[46] Melissa, Dumas., Binita, Kc., Colin, I., Cunliff. (2019). Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods. doi: 10.2172/1558514.

[47] Ibid 25.

5. Vulnerability Analysis for the Project's Location

5.1. Geographic and Structural Resilience

The National Multi-Hazard Early Warning Center, housed within the Directorate General of Meteorology in the Seeb Province of Muscat, is designed to minimize vulnerability to climate risks (**Figure 57** & **Figure 58**). The headquarters, inaugurated in 2015, was constructed with robust safety norms and climate-proofing measures. Situated 6 meters above sea level, the building's elevation significantly reduces the risk of flooding. Additionally, the center boasts a well-designed drainage system, further mitigating potential flood impacts. These structural advantages, combined with modern construction standards, provide a solid foundation for the center's resilience against various climate threats.

Figure 57: Geographical Location of the National Multi-Hazard Early Warning Center in Muscat, Oman

Figure 58: The New Headquarters Building: Home of the National Multi-Hazard Early Warning Center within the Directorate General of Meteorology.

5.2. Climate Threats

Despite its resilient design, the National Multi-Hazard Early Warning Center remains susceptible to the impact of a direct tropical cyclone landfall. Flooding, while mitigated by the center's elevation and drainage systems, can still pose a significant risk during such extreme weather events. Tropical cyclones can bring heavy rainfall and storm surges that may overwhelm existing flood defenses. Additionally, the high winds associated with cyclones can damage physical infrastructure and disrupt essential communication networks, compromising the center's operational capabilities. The increased intensity and frequency of these cyclonic events highlight the ongoing vulnerability and the need for continuous improvement in the center's preparedness and response strategies.

5.3. Operational Vulnerability

The operational vulnerability of the National Multi-Hazard Early Warning Center is addressed through several critical measures, including the installation of backup power systems. These systems are essential for ensuring that operations can continue uninterrupted during power disruptions caused by extreme weather events. Reliable communication networks are crucial for the center's functionality; however, these can be compromised during severe weather conditions. Additionally, while the center's location is well-connected by roads, extreme weather events could block or damage access routes, affecting the center's ability to respond swiftly and efficiently to emerging threats.

5.4. Adaptation and Mitigation Measures

To combat the various climate risks, the National Multi-Hazard Early Warning Center has implemented several adaptation and mitigation measures. Infrastructure enhancements are continually made to ensure the building can withstand increasingly severe weather events. Comprehensive emergency protocols are in place, allowing for rapid response and ensuring the continuity of operations during and after climate-related incidents. The center also relies on redundancy systems, including backup power and communication networks, to maintain uninterrupted functionality. These measures collectively strengthen the center's ability to manage and mitigate the impacts of extreme weather, ensuring its critical early warning systems remain operational.

Overall, the National Multi-Hazard Early Warning Center in Oman is well-positioned to withstand climate risks due to its strategic location, robust construction, and effective infrastructure. The combination of high safety standards, climate-proofing measures, and advanced drainage systems significantly mitigates potential vulnerabilities. Furthermore, the inclusion of backup power systems and comprehensive emergency protocols enhances the center's operational resilience. Continuous infrastructure updates and stringent monitoring are essential to address evolving climate threats, ensuring the center can maintain its vital role in providing early warnings and protecting the population from the adverse effects of climate change.

6. Strategic Climate Policy Framework

6.1. Alignment with International Climate Commitments

Oman has demonstrated a long-standing commitment to international climate agreements, beginning with its signing of the UNFCCC on June 11, 1992. The Sultanate ratified the UNFCCC on February 8, 1995, officially marking its entry into force on May 9, 1995, as a Non-Annex I party. This initial step was further reinforced when Oman acceded to the Kyoto Protocol on January 19, 2005, with the Protocol taking effect on April 19, 2005. These actions aligned Oman with the broader goals set forth during the Earth Summit in Rio de Janeiro in 1992, committing to the comprehensive approaches required under the UNFCCC framework to combat climate change.

As a party to the UNFCCC, Oman is obligated to fulfill several key requirements. These include the submission of national communications that provide detailed inventories of anthropogenic emissions and outline national strategies for mitigating climate change. Such inventories and national measures are crucial for adhering to Article 4.1 and Article 12.1 of the UNFCCC, ensuring that all efforts are comparable, credible, and based on methodologies agreed upon by the Conference of the Parties. Additionally, these communications encompass adaptation measures and outline the communication for international climate finance necessary to combat the exacerbation and accelerated impact of climate risk that Oman faces.

Oman's Initial Communication with the UNFCCC was submitted in 2013, followed by the Second Communication in 2019. Additionally, the Sultanate submitted its Biennial Update Report (BUR) in 2019, showcasing its ongoing commitment to transparency and reporting. Additionally, these communications encompass adaptation measures and highlight the need for international climate finance to combat the exacerbation and accelerated impact of climate risks that Oman faces.

The adoption of the Paris Agreement during the COP21 negotiations in December 2015 marked a significant evolution in the global response to climate change. Oman signed the Paris Agreement on April 22, 2016, and ratified it on May 22, 2019.

Oman's commitment to the Paris Agreement is further demonstrated by its submission of the NDC in 2021. In 2023, the country updated its Second NDC, raising its ambition to further reduce emissions by 2030. This new commitment aligns with the Oman Vision 2040, which outlines a strategic framework for sustainable development, economic diversification, and environmental stewardship. The Vision 2040 plan emphasizes the importance of transitioning to a low-carbon economy, increasing the share of renewable energy, and enhancing energy efficiency across various sectors.

Furthermore, this enhanced NDC is a critical step towards achieving Oman's goal of climate neutrality by 2050. The orderly transition to climate neutrality involves comprehensive measures to reduce greenhouse gas emissions, promote clean energy technologies, and implement sustainable practices across industries. By aligning its NDC with these long-term objectives, Oman demonstrates its dedication to global climate action and its proactive approach to mitigating the impacts of climate change while ensuring economic resilience and sustainability for future generations. This ongoing commitment highlights Oman's dedication to aligning its national climate policies with international standards and contributing to global efforts to combat climate change. In addition to these mitigation efforts, Oman has made significant progress in implementing adaptation measures to enhance resilience against climate impacts. However, the country emphasizes in its NDC communication the critical need for international climate finance to support these adaptation initiatives and bolster its overall resilience to the escalating risks posed by climate change. To date, Oman has not received substantial climate finance for either adaptation or mitigation efforts.

6.2. National Institutional Actions on Climate Change Adaptation

6.2.1. National Strategy for Adaptation and Mitigation to Climate Change (2020-2040)

In April 2019, Oman approved a 20-year National Strategy for Adaptation and Mitigation to Climate Change. The Strategy's vision focuses on three integrated themes: (i) climate science, which includes an analysis of historical climate trends, projections of future climate change, and the development of climate information, regional climate modeling, air monitoring, and strategic research actions; (ii) vulnerability and adaptation, which examines the vulnerabilities to climate change of Oman's priority sectors and forms the basis for a climate change adaptation strategy; and (iii) sustainable development. These themes were identified based on five primary objectives that underline Oman's priorities: (i) building institutional capacity to address climate change challenges; (ii) encouraging awareness-raising of climate change across relevant public and private sector groups; (iii) developing climate research to improve access to climate change data; (iv) ensuring sector-specific policies are developed; and (v) addressing national and international needs.

The National Strategy was built using climate projections based on the Representative Concentration Pathway (RCP) scenarios for 2041–2060 and 2061–2080 at a spatial resolution of 1 km through statistical downscaling techniques. National stakeholders have highlighted low-carbon and climate-resilient potential in five critical sectors: water resources, marine biodiversity and fisheries, agriculture, urban areas, tourism and infrastructure, and public health. Before identifying the ultimate adaptation alternatives for each sector and mainstreaming adaptation into sectoral processes and ministry portfolios, more investigation and support are needed. This readiness plan will build adaptation strategies for each sector and line ministry to reduce climate change risks. Accordingly, Oman's NAP process relies on the Climate Change Strategy for its knowledge base, which informs Oman's readiness proposal activity flow. This readiness proposal will outline the terms of reference for the Climate Change Strategy's strategic vision and NAP process goals. In addition, the readiness plan will increase governance and institutional coordination, identify policy priorities, mobilize resources, and allocate the necessary support to track sectoral progress and achieve adaptation goals.

6.2.2. Intended Nationally Determined Contributions (2015)

The Sultanate of Oman signed the Paris Agreement and submitted its INDC to combat climate change in 2015 with a commitment to reduce their absolute carbon emissions by 2% by 2030. The INDC prioritizes both mitigation and adaptation. It lists cyclones, coastline erosion, sea-level rise, floods, water scarcity, and desertification as Oman's top threats. Future climate change is expected to cause heatwaves, coastal erosion, and reduced fish yield, which will impact Oman's agriculture and marine ecosystems. The INDC highlights capacity development and technology transfer in the fisheries, marine environment, water resources, energy, and food security sectors.

6.2.3. Second Nationally Determined Contributions (2021) and its update (2023)

Oman submitted its Second NDC to the UNFCCC in 2021, aiming to reduce GHG emissions by 7% by 2030. In 2023, this NDC was updated, raising the GHG reduction target to 21% by 2030. The Second NDC and its update highlight Oman's commitment to prioritizing numerous sensitive sectors for adaptation: water resources, marine biodiversity and fisheries, agriculture, urban areas, tourism and infrastructure, and public health. This NDC aligns with the vulnerable sectors identified in the Climate Change Strategy. The Second NDC identified barriers hindering climate change adaptation efforts in Oman, including limited data, information, and knowledge on climate change vulnerability; limited experience with methods and tools to support climate-risk informed decision-making processes in crucial sectors; insufficient national budgets to adequately address the scope and magnitude of climate change impacts; and inadequate national resourcing. This readiness proposal will help address these barriers by assessing climate risk and vulnerability, developing an online climate risk information portal, mainstreaming adaptation priorities into sector plans and budgets, and finalizing a gender-sensitive National Adaptation Monitoring Framework for Oman. The Second NDC supports Oman's National Adaptation Plan (NAP) and integrates climate change adaptation into development planning. It recognizes climate economics and finance as key to achieving this goal, with the readiness plan aiming to improve the NAP process by increasing adaptation financing.

6.2.4. National Communications (2013 and 2019)

Oman's Initial National Communication was presented to the UNFCCC in 2013. To fulfill Oman's international obligations, the INC noted the steady progress in diversifying Oman's economy away from its reliance on oil, hence the selection of critical areas. The INC selected coastal zones, water resources, and the marine environment as the Sultanate of Oman's most vulnerable regions, aligning with the updated priority sectors for this readiness proposal.

The Second National Communication, presented in 2019, prioritizes the same sectors as the NDC and Climate Change Strategy. The SNC explains strategic actions for each priority sector that informed this readiness plan, including improving access to climate information; strengthening climate data development and monitoring; maintaining the research and development base to enable ongoing evaluation of climate change impacts; conducting additional scientific studies such as CBA of adaptation and mitigation options; and launching a Climate Change Research Centre to conduct scientific research. This readiness proposal will contribute to strategic activities by building an online national portal of climate risk information, including gender-sensitive indicators, and performing a CBA of adaptation measures.

6.3. Ongoing and Recently Completed Adaptation Projects

6.3.1. GCF Readiness and Preparatory Support and Country Program (2016 and 2019)

In 2016, Oman initiated GCF Readiness and Preparatory Support, which strengthened the former Ministry of Environment and Climate Affairs' institutional capacity and awareness of the GCF, notably the GCF (NDA) role and functions. The Ministry of Environment and Climate Affairs learned how to interface with the GCF's climate financing environment, assess climate investment opportunities, and engage with the private sector. The RPS led to accreditation support for a direct access entity, the establishment of Oman's Country Program, dissemination of GCF information to key stakeholders, and enhanced knowledge of GCF's engagement benefits and prospects in the private sector.

Oman's GCF Country Program (2019) prioritizes GHG mitigation in the energy sector, recognizing that climate change-related threats have increased in recent years, as demonstrated by changes in the number, duration, and intensity of tropical cyclones, heatwaves, and rising sea levels. These threats have increased water scarcity, impacted fishing productivity, reduced food yields, put pressure on urban infrastructure, and posed public health risks. The Country Program aims to improve stakeholders' awareness of the GCF's processes for Climate Change Adaptation and mitigation initiatives. It presents a framework for successful adaptation and mitigation efforts, concentrating on knowledge management, capacity building, and governance for Oman's five vulnerable sectors: water resources; fisheries and marine resources; agriculture; infrastructure, including urban areas and tourism; and public health.

6.3.2. Building Resilient Environment and Sustainable Agriculture and Water (2022-2024)

Oman is a regional hotspot where global warming is projected to exceed the threshold for ecological survival. Increased temperatures and decreased rainfall will exacerbate Oman's water scarcity and strain the country's already-limited freshwater resources, both in quantity and quality. With agriculture consuming over 90% of available freshwater, the problem is persistent and aggravated. To address these growing and complex challenges, the Government of Oman, in collaboration with FAO, developed a GCF readiness program to strengthen the development of ranked and prioritized agriculture/water-related projects/concept notes and develop a concept note using robust knowledge about the impact of climate change on primary crops and climate-resilient alternatives. This ongoing readiness program seeks to set up climate change metrics for the agriculture sector and assess climate information and farmer advisory gaps. Additionally, the project aims to strengthen enabling environments for GCF programming in low-emissions investment and ensure a more effective response to the impacts of climate change on food security and livelihoods.

6.3.3. National Adaptation Plan (2023-2026)

Oman's NAP identifies its medium- and long-term climate adaptation needs, strategies, and programs that need to be developed and implemented to address those needs. These planning processes are intended to catalyze action and finance to generate systemic change that addresses climate impacts and vulnerabilities. It is country-driven and based on Oman's key national and sectoral priorities, including its Nationally Determined Contributions and National Adaptation Program of Action. Some of the indicators the project will use include humidity, mean annual temperature, sea-level rise, and extreme events such as floods, rainfall, storms, and cyclones.

The Readiness proposal will support the ongoing NAP process in the Sultanate of Oman, which aims to strengthen the implementation of the adaptation components of the National Strategy for Adaptation and Mitigation to Climate Change 2020-2040. Specific barriers identified through background research and stakeholder consultations can be grouped into six areas: (i) inadequate national policy/legal framework for mainstreaming climate change adaptation; (ii) minimal progress in identifying, addressing, and mainstreaming sectoral vulnerabilities in national policies; (iii) limited availability of evidence-based decision support information at the sectoral level; (iv) limited analysis and knowledge on gender and socially differentiated impacts and vulnerabilities; (v) limited societal awareness of climate change impacts and resilience trajectories; and (vi) limited private sector awareness and engagement in Climate Change Adaptation.

The overall objective is to allow the Sultanate of Oman to plan for the long-term impacts of climate change, particularly for the following sectors: (i) water resources; (ii) agriculture; (iii) fisheries and marine resources; (iv) infrastructure, including urban areas and tourism; and (v) public health. The project activities will primarily benefit the government and other stakeholders, including the private sector, civil society, academia, and the general public.

6.4. Strengthening the National Multi-Hazard Early Warning System in Oman: Project Developed within the Ongoing GCF NAP

The project idea for Strengthening the National Multi-Hazard Early Warning System in the Sultanate of Oman stems from the ongoing GCF readiness project (2023-2026). Within the National Adaptation Plan (NAP), it was planned to develop five project ideas, with three of them to be transformed into GCF concept notes. The NAP project provided an ideal framework for consultation with stakeholders, allowing for the development of the concept note and the funding proposal.

This process involved extensive stakeholder engagement, ensuring that the project aligns with national priorities and addresses the specific needs and vulnerabilities identified through the NAP. The collaborative approach facilitated through the NAP project ensures that the proposed early warning system is comprehensive, effectively integrates climate risk information, and enhances Oman's capacity to respond to and manage multiple hazards.

Building on the foundational work of the GCF readiness project, this initiative aims to significantly improve the resilience of Oman's infrastructure and communities to the increasing threats posed by climate change, ensuring a proactive and well-coordinated response to future emergencies. The project leverages existing resources and knowledge, while also introducing new technologies and practices to enhance early warning capabilities.

The Strengthening the National Multi-Hazard Early Warning System project represents a strategic advancement in Oman's climate resilience efforts. It is a direct outcome of the structured and consultative process established through the NAP, highlighting the country's commitment to sustainable development and proactive disaster risk management.

Integrating comprehensive climate risk information and fostering a collaborative approach among stakeholders, the project is poised to play a crucial role in safeguarding Oman's infrastructure and communities against the escalating impacts of climate change.

7. Climate Change Governance

7.1. Evolution of Climate Change Management in Oman

Oman's journey in environmental governance began with the establishment of the Office of the Environmental Protection Adviser in 1974. This was followed by the creation of a public agency for environmental protection and pollution control under Royal Decree No. 14/79, and subsequently, the establishment of the Environmental Protection and Pollution Control Council in 1979 by Royal Decree No. 68/79. The Ministry of Environment came into existence in 1984 under Royal Decree No. 45/84, leading to a series of decrees culminating in the announcement of the Ministry of Environment and Climate Affairs as an autonomous entity in 2007 by Royal Decree No. 90/2007.

Further enhancing this framework, 2008 saw the issuance of Royal Decree No. 18/2008, which delineated the mandate of the Ministry of Environment & Climate Affairs and approved its organizational structure, including the establishment of a new Directorate General of Climate Affairs. The Environment Authority was established in August 2020 as per Royal Decree No. 106/2020, taking over climate-related responsibilities from the Civil Aviation Authority according to Royal Decree No. 2022/60.

The responsibilities of the Environment Authority in addressing climate change encompass:

- Monitoring and assessing climate change to ensure the protection of environmental, social, and economic systems;
- Supporting the advancement of scientific research in climate-related fields, facilitating the exchange of knowledge, and accumulating and utilizing scientific data;
- Educating and fostering an understanding among all societal segments about adapting to severe climate conditions;
- Drafting proposed laws and royal decrees concerning climate affairs, and issuing regulations and directives under these laws and decrees;
- Strengthening and expanding cooperation in climate-related areas with relevant entities, other countries, and regional and international organizations and institutions;
- Executing the mandates of international climate agreements to which the Sultanate is a signatory.

7.2. Organizational Structure of Climate Affairs

The organizational structure of climate affairs within the Environment Authority is designed to address various aspects of climate change through specialized departments and initiatives. These include:

- **Climate Change Mitigation**
    - Participate in the preparation and implementation of climate laws, regulations, and guidelines to reduce greenhouse gas emissions.
    - Develop and support initiatives aimed at transitioning to renewable energy sources and improving energy efficiency.
- **Adaptation to Climate Change**
    - Participate in the preparation and implementation of climate adaptation laws, regulations, and guidelines to enhance resilience against climate impacts.
    - Implement programs and projects aimed at adapting to climate variability and protecting vulnerable sectors and communities.
- **Modeling & Climate Studies**
    - Conduct climate modeling and studies to understand future climate scenarios and their potential impacts on Oman.
    - Use climate data and models to inform policy decisions and adaptation strategies.

7.3. Oman's Response to Climate Risk: Establishment of the National Emergency Fund

As the intensity and frequency of tropical cyclones along Oman's coast increase due to climate change, the government has proactively established the National Emergency Fund on January 1, 2024. This initiative aims to address urgent situations and natural disasters—ranging from climatic events and floods to earthquakes and other hazards—that cause damage to public facilities and infrastructure. It underscores the critical importance of a swift and effective response to emergencies that significantly impact the nation. The fund is designed to support the implementation of public policy related to emergency management procedures, enhancing Oman's readiness and resilience against natural disasters. It also provides necessary funding to facilitate a swift recovery and return to normalcy following emergencies.

The resources of the National Emergency Fund include allocations from the state budget, ensuring a steady flow of financial support. Gifts, donations, and contributions accepted by the Minister of Finance broaden the fund's financial base. Returns on the investment of the fund's resources further increase its capacity, while other resources approved by the Cabinet allow flexibility to adapt to emerging needs.

The Minister of Finance is empowered to make necessary decisions to effectively manage and regulate the fund. This includes managing the fund's assets and adopting investment strategies that align with established financial policies, establishing committees to achieve the fund's objectives, setting project tendering rules, and endorsing financial reports to maintain transparency and accountability. Additionally, the fund is responsible for preparing post-emergency reports in coordination with relevant entities to research and develop strategies that mitigate future risks, as well as regulating the reception of cash donations during and after emergencies to ensure proper management and allocation of resources.

The fund maintains a separate annual budget with surpluses rolling over each year, ensuring sustained funding. Its assets are considered public funds and are thus subject to the rigorous standards of the penal code and financial and administrative control laws. Importantly, decisions and contracts made by the Minister of Finance in direct and immediate response to emergencies are granted exemptions from general and specific legal stipulations, enabling rapid action. By establishing the National Emergency Fund, Oman strengthens its capacity to manage and respond to the increasing challenges posed by climate change, ensuring the safety and stability of its infrastructure and communities.

8. Current Status of the Early Warning Services in Oman

8.1. Establishment and Purpose

Recognizing the challenges posed by tropical cyclones, Oman established the NMHEWS under the Directorate General of Meteorology, highlighting Oman's proactive approach to managing climate risks. The NMHEWS in Oman was established to address water-related hazards, including threats from Makran and Sunda Trench tsunamis, tropical cyclones, and flash floods. This system's inception was facilitated with technical expertise from the Intergovernmental Oceanographic Commission, marking the beginning of their collaborative efforts in 2009. By 2010, both the Intergovernmental Oceanographic Commission and Omani authorities were working together to shape the Tsunami Early Warning System (TEWS), which was integrated into NMHEWS. This collaboration aimed to bolster Oman's ability to predict and respond to natural disasters, thereby minimizing their impact on the country's infrastructure and population.

The NMHEWS was formally unveiled on March 23, 2015, in Muscat, Oman. This launch coincided with the regional Conference on Reducing Tsunami Risk in the Western Indian Ocean and the Tenth Session of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System. The official launch marked a significant milestone in Oman's journey towards enhanced disaster preparedness and risk management.

8.2. Management and Services

The Directorate General of Meteorology in the Civil Aviation Authority is responsible for managing the NMHEWS. The Directorate employs a large staff of 231 people who work across the country to collect data and issue warnings in the event of a natural hazard. The Directorate manages various weather monitoring stations and tools across Oman, including:

- 5 marine stations that monitor oceanographic conditions
- 75 surface stations that track weather patterns
- 6 HF wave radars that detect sea state and wave conditions
- 10 sea level stations that monitor changes in sea level
- 10 GPS stations that provide precise location data
- 2 upper air stations that measure atmospheric conditions at higher altitudes
- 5 weather radars that provide comprehensive weather surveillance

These stations and tools are used to collect data on weather patterns, ocean conditions, and other environmental factors that can impact Oman. The NMHEWS has benefited from various training sessions, capacity-building measures, and the establishment of sea-level stations provided through collaboration with IOC-UNESCO. This extensive network of monitoring stations enables the Directorate to provide timely and accurate early warnings to the public and relevant authorities.

NMHEWS adheres to the Sendai Framework, which promotes a renewed approach to generating, assessing, and using risk information in early warning systems, disaster prevention strategies, and government policies. This Framework emphasizes the significant role of early warnings in both disaster risk reduction and sustainable development. By aligning with the Sendai Framework, NMHEWS ensures that its operations are in line with international best practices for disaster risk management.

Following the first Multi-Hazard Early Warning Conference hosted by IN-MHEWS in Cancún, Mexico, in 2017, NMHEWS adopted a specific checklist to refine its mission and vision. The NMHEWS is committed to further refining and expanding its mission and vision to fully align with the essential checklist components:

- Cultivating disaster risk knowledge through systematic data accumulation and risk evaluations, ensuring a comprehensive understanding of potential hazards.
- Proficient hazard detection, monitoring, analysis, and forecasting alongside possible implications, allowing for accurate predictions and timely responses.
- Efficient, timely, and accurate warning dissemination from trusted sources, paired with insights on potential impacts, ensuring that all relevant stakeholders are informed and prepared.
- Ensuring preparedness at every tier to act in response to the disseminated warnings, promoting a culture of readiness and resilience among the population and emergency services.

8.3. Other Early Warning Services

Since 1990, the Ministry of Agriculture, Fisheries, and Water Resources in Oman has established a monitoring system aimed at comprehensively assessing the country's hydrological and meteorological conditions. This system includes a network of gauges strategically placed to monitor wadi flows, which play a crucial role in understanding the flow dynamics and recharge patterns. Additionally, the ministry maintains a network of boreholes to monitor groundwater resources, providing valuable data on the condition of the aquifers. To supplement rainfall data collection, a series of meteorological stations has been strategically positioned in mountainous regions, where rainfall is particularly significant. These stations contribute essential data to enhance the nationwide meteorological network managed by the Directorate General of Meteorology.

However, a significant gap exists as the Ministry of Fisheries' monitoring stations aren't integrated with the meteorological department's early warning system. This lack of connectivity can hinder efficient information exchange and timely alerts, posing potential risks and impeding resource management. Addressing this gap by integrating these monitoring systems would improve the overall effectiveness of Oman's early warning services, ensuring a more coordinated and comprehensive approach to disaster risk management.

8.4. SWOT Analysis of Existing Early Warning Systems in Oman

8.4.1. Strengths

1. **New Headquarters**: The headquarters, inaugurated in 2015, was constructed with robust safety norms and climate-proofing measures, enhancing the system's overall resilience.
2. **Comprehensive Monitoring Network**: The Directorate General of Meteorology manages an extensive network of monitoring stations, including marine, surface, HF wave radars, sea level stations, GPS stations, upper air stations, and weather radars, allowing for detailed data collection on various environmental factors.
3. **Dedicated Workforce**: The Directorate employs a large staff dedicated to monitoring and managing data, supporting the efficient operation of the early warning system.
4. **International Collaboration**: Collaboration with Intergovernmental Oceanographic Commission provides significant technical expertise, enhancing the capability of NMHEWS and aligning it with international standards.
5. **Adherence to the Sendai Framework**: NMHEWS aligns with the Sendai Framework, ensuring operations meet international best practices for disaster risk reduction and sustainable development.

8.4.2. Weaknesses

1. **Limited Integration**: The monitoring stations managed by the Ministry of Agriculture, Fisheries and Water Resources are not integrated with the meteorological department's early warning system, leading to inefficiencies in information exchange and resource management.
2. **Resource Constraints**: There are limitations in resources and funding to expand or upgrade existing systems, which affects the overall effectiveness and reach of early warning services.
3. **Operational Challenges**: Managing multiple monitoring stations and ensuring real-time data accuracy pose significant operational challenges.
4. **Coverage Gaps**: The NMHEWS does not adequately cover crucial climate risks such as heat waves, droughts, dust storms, and flooding, limiting its effectiveness in providing comprehensive early warnings.
5. **Forecasting Accuracy**: The NMHEWS faces challenges in providing precise and timely early warnings due to the rapid rate of climate change and the escalating frequency and severity of climate-related disasters. The preparedness plan for tropical cyclones is constrained by low forecasting accuracy and challenges in predicting the spatial distribution of associated rainfall due to the absence of comprehensive weather radar observations.
6. **Effective Warning Dissemination**: The scope of the early warning center is limited, obstructing efforts to develop effective response strategies and preparedness plans, leading to the loss of life, widespread damage to infrastructure, and long-term social and economic consequences.
7. **Capacity Building**: There is a need to enhance the capacity of Oman's existing early warning center by improving the precision and timeliness of forecasts and expanding its coverage to other significant climate risks.
8. **Preparedness Deficiencies**: There is a significant deficiency in effective disaster preparedness measures and response plans for various climate phenomena, including tropical cyclones.
9. **Preparedness Measures**: The center lacks robust knowledge and response plans for climate phenomena like heat waves, droughts, dust storms, and flooding.
10. **Lack of Climate Information Services Tailored to the Needs of Planners**: There is a significant gap in climate information services tailored to the specific needs of planners in different sectors, hindering effective decision-making and planning.

8.4.3. Opportunities

1. **Investment in Advanced Technologies**: Investing in advanced technologies can enhance monitoring and data analysis capabilities, leading to more accurate and timely early warnings.
2. **International Partnerships**: Continued collaboration with international organizations can bring additional technical expertise and funding opportunities.
3. **Integration of Systems**: Integrating the monitoring stations of the Ministry of Fisheries with the meteorological department's systems can enhance efficiency and data sharing.
4. **Strengthening Climate Information Services**: Enhancing climate information services can improve the accuracy and reliability of data used for early warnings and decision-making.
5. **Promoting Impact-Based MHEWS and Early Action**: Developing and implementing impact-based Multi-Hazard Early Warning Systems can ensure timely and effective responses to climate threats.
6. **Improving Climate Information and Early Warning System for Investments in Climate-Resilient Infrastructure**: Upgrading climate information and early warning systems can support investments in infrastructure that is resilient to climate impacts.
7. **Public Awareness Campaigns**: Increasing public education and awareness campaigns can ensure the population is better prepared to respond to early warnings.
8. **Capacity Building and Training**: Ongoing training and capacity-building initiatives can further improve the skills and knowledge of the staff managing the early warning systems.
9. **Alignment with International Standards**: Oman's commitment to aligning with the checklist components established at the inaugural Multi-Hazard Early Warning Conference and the "Early Warnings for All" initiative emphasizes strengthening the capacity of the National Multi-Hazard Early Warning System. This entails investments in advanced technologies, fostering collaborations, building human capacity, raising public awareness, and promoting preparedness.
10. **Engagement of Private Sector:** Early warning services help insurance companies improve risk assessment, proactive management, and customer service, while reducing losses and enhancing operational efficiency. This leads to more resilient and innovative insurance operations.

8.4.4. Threats

1. **Increasing Climate Change Impacts**: The increasing frequency and intensity of climate-related events such as tropical cyclones and flash floods pose ongoing threats that the system must continuously adapt to.
2. **Funding Limitations**: There may be limitations in securing sufficient funding to maintain and upgrade early warning systems and expand their reach.
3. **Technical Failures**: The potential for technical failures in monitoring equipment or communication systems could undermine the effectiveness of early warnings.
4. **Coordination Issues**: Inefficiencies in coordination between different government departments and agencies could hinder the timely dissemination of warnings and response efforts.
5. **Limited Coverage by Existing Climate Information Services**: The state of weather radar systems suffers from lack of maintenance and outdated technology, which undermines the efficiency of tracking significant weather phenomena like tropical cyclones.
6. **Inadequate Infrastructure for Climate Information Systems**: There is an inadequate quality of hard and soft infrastructure for climate information modeling, monitoring, and forecasting systems, including the absence of a dynamic web-GIS-based early warning system.
7. **Inadequate Observation Networks**: There are insufficient observation networks and limited capacity at the EWS center, which lacks institutional support and coordination.
8. **Limited Awareness and Use of Climate Hazard Information**: Limited public awareness and use of climate hazard and risk information are exacerbated by the absence of an advanced media center and qualified personnel.
9. **Public Complacency**: Over time, there is a risk of public complacency if early warnings are not accompanied by visible impacts or if the public perceives them as false alarms.
10. **Urban Planning Deficiencies**: The failure to incorporate flood-prone areas into urban plans and insufficient mapping, particularly in rapidly expanding cities like Muscat, Al Bathina, Salalah, Sur, and Sohar, poses a significant threat.
11. **Lack of Climate Resilience in Urban Expansion**: Lack of consideration for climate resilience needs in urban expansion leads to infrastructure vulnerability to climate-induced damages.
12. **Limited Private Sector Investment**: Private sector and community investments in climate-resilient infrastructure are limited, which is vital for long-term sustainability and resilience against climate threats.

Chapter 2: Feasibility Assessment

1. Technical Assessment

The Sendai Framework for Disaster Risk Reduction 2015-2030, adopted by the United Nations, emphasizes the importance of understanding disaster risk in all its dimensions and outlines four essential pillars for effective disaster risk reduction:

- Understanding Disaster Risk (Risk Knowledge): This pillar involves collecting, analyzing, and disseminating information on hazards, exposures, vulnerabilities, and capacities to develop targeted and effective early warning systems and enable informed decision-making.
- Strengthening Disaster Risk Governance to Manage Disaster Risk (Monitoring and Warning Service): This pillar focuses on establishing and strengthening policies, institutions, and legal frameworks to manage disaster risk effectively and enhance coordination among stakeholders.
- Investing in Disaster Risk Reduction for Resilience (Dissemination and Communication): This pillar emphasizes the need for investing in infrastructure, technology, and resources to reduce disaster risk and build resilience across communities and sectors.
- Enhancing Disaster Preparedness for Effective Response and to “Build Back Better” in Recovery, Rehabilitation, and Reconstruction (Response Capability): This pillar aims to enhance preparedness for effective response and recovery, ensuring that communities can "build back better" after disasters.

The GCF funding proposal primarily focuses on strengthening the first three pillars of the Sendai Framework for Disaster Risk Reduction within the context of Oman. The multi-hazard early warning center aims to bolster these pillars by integrating advanced technologies and innovative solutions. The proposed technical options and specifications for equipment and infrastructure are meticulously defined for each pillar, ensuring their suitability and innovative potential. These enhancements are designed to significantly improve the center's capabilities in monitoring, analyzing, and responding to a range of hazards, thereby increasing Oman's resilience and preparedness.

1.1. Technical Solutions and Specifications for Equipment and Infrastructure for Risk Knowledge

To enhance risk knowledge and improve the effectiveness of the multi-hazard early warning center in Oman, the following technical solutions and specifications for equipment and infrastructure are proposed in **Table 6.**

Table 6: Technical Solutions and Equipment Specifications for Improving Risk Assessment Capabilities

Sendai Pillar	Technology and Technical Equipment	Number	Utility for Climate Risk and Multi-Hazard Early Warning System in Oman
Risk Knowledge	Geographic Information Systems (GIS) Platform: ArcGIS Suite (1 License for 28 software)	1 License	Enhance mapping, spatial analysis, and real-time data processing for risk-prone areas. Includes: - ArcGIS Online: Cloud-based mapping and data analysis. - ArcGIS GeoPlanner: Scenario planning for climate impacts. - ArcGIS Image for ArcGIS Online: Satellite imagery processing. - ArcGIS Insights: Advanced analytics and data visualization. - ArcGIS Notebooks: Scripting and automation of data workflows. - ArcGIS Velocity: Real-time data ingestion and analysis. - ArcGIS Enterprise: Server-based data management. - ArcGIS GeoAnalytics Server: Big data analysis. - ArcGIS GeoEvent Server: Real-time data stream processing. - ArcGIS Image Server: Imagery and raster data management. - ArcGIS Network Analyst: Evacuation route planning. - ArcGIS Pro: Advanced spatial analysis and mapping. - ArcGIS 3D Analyst: 3D terrain and flood scenario visualization. - ArcGIS Geostatistical Analyst: Statistical analysis for prediction. - ArcGIS Image Analyst: Information extraction from satellite imagery. - ArcGIS Spatial Analyst: Complex spatial analysis for risk modeling. - ArcGIS Dashboards: Real-time monitoring dashboards. - ArcGIS Experience Builder: Custom web applications. - ArcGIS Field Maps: Mobile data collection. - ArcGIS QuickCapture: Rapid field data capture. - ArcGIS Survey123: Community feedback surveys. - ArcGIS GeoAnalytics Engine: Distributed computing for large datasets. - ArcGIS Reality: Reality capture data integration. - Site Scan for ArcGIS: Drone imagery for high-resolution mapping. - Location Data: Environmental data, imagery, and movement data for risk assessment.
	Computers: High-performance workstations	10	Handle advanced GIS, data analysis, and simulation tasks efficiently.
	Fixed-wing drones	8	For large-scale mapping of Oman's diverse landscape, including coastal areas, mountains, and deserts.
	Multirotor drones	15	For detailed inspections in urban areas, industrial zones, and critical infrastructure.
	VTOL drones	5	For combining long-range capabilities with precision in hard-to-reach areas like wadis and mountain regions.
	Waterproof/Amphibious drones	5	For monitoring coastal areas, potential flood zones, and during the khareef season in Dhofar.
	Thermal Imaging Equipped drones	8	For heat mapping in urban areas and potential wildfire detection in mountainous regions.
	LiDAR Equipped drones	3	For high-precision terrain mapping, particularly in areas prone to flash floods.
	Long-endurance drones	3	For continuous monitoring of large desert areas and coastal zones.
	Swarm Drones (sets of 5-10 drones each)	2 sets	For rapid response and wide-area coverage during emergencies like cyclones.

	AI data analysis	1 License each	Enable predictive analytics and risk modeling.
	Modeling and simulation tools	1 License	Simulate potential hazard impacts and scenarios.
	Increase the existing high-performance computing system to 800 teraflops	1 System	Handle large datasets and complex simulations efficiently for climate modeling and Numerical Weather Prediction Model .

The proposed technical solutions and specifications for equipment and infrastructure are designed to significantly enhance the risk knowledge and operational capabilities of the multi-hazard early warning center in Oman. Integrating advanced GIS platforms, high-performance computing, diverse drone technologies, AI data analysis, and sophisticated modeling tools, the center will be well-equipped to monitor, analyze, and respond to various hazards. This approach aligns with the four pillars of the Sendai Framework, ensuring a comprehensive, innovative, and effective disaster risk reduction strategy that enhances resilience and preparedness across multiple sectors in Oman.

1.2. Evaluation of Technology Suitability and Innovation for Enhancing Risk Knowledge in the Multi-Hazard Early Warning Center in Oman

1.2.1. Geographic **Information** Systems Platform

The ArcGIS Platform provides a comprehensive range of tools for mapping, spatial analysis, and data visualization, making it highly suitable for the multi-hazard early warning center in Oman. The platform's ability to integrate various data sources and perform real-time analysis is crucial for effective hazard monitoring and early warning.

The ArcGIS Platform includes cutting-edge tools such as ArcGIS Velocity for real-time data ingestion and analysis, ArcGIS Insights for advanced analytics, and ArcGIS GeoAnalytics Server for big data processing. These innovations enable the center to perform complex spatial analyses and generate accurate risk assessments, enhancing decision-making capabilities.

The ArcGIS Platform's capabilities enable the production of customized climate information for various sectors. Planners in agriculture can use GIS for assessing drought risk and optimizing irrigation. Urban planners can utilize flood risk maps to design resilient infrastructure. Emergency responders can leverage real-time data for effective disaster management. The ability to create sector-specific dashboards and reports ensures that all stakeholders receive relevant and actionable climate information.

1.2.2. High-**performance** Workstations

The high-performance workstations equipped with powerful processors and GPUs are essential for managing and processing large datasets, running sophisticated GIS applications, and conducting simulations. Their robustness ensures reliability and efficiency in handling the computational demands of the early warning center.

Leveraging the latest processor technologies and high-end GPUs, these workstations represent the forefront of computing innovation, providing the necessary computational power to support advanced GIS analytics and real-time processing required for effective early warning systems.

1.2.3. **Drone** Technologies

Drones are versatile tools for comprehensive hazard assessment and monitoring in diverse landscapes such as coastal areas, mountains, and urban environments.

- **Fixed-wing drones:** Ideal for extensive aerial surveys and mapping, covering large geographical areas with high efficiency.
- **Multirotor drones:** Suitable for detailed inspections and monitoring in urban environments, industrial zones, and critical infrastructure.
- **VTOL drones:** Access hard-to-reach areas such as wadis and mountain regions, combining long-range flight with precise vertical takeoff and landing.
- **Waterproof/Amphibious drones:** Essential for monitoring coastal zones and flood-prone areas, especially during the khareef season in Dhofar.
- **Thermal Imaging Equipped drones:** Crucial for detecting heat anomalies, such as wildfires, and conducting heat mapping.
- **LiDAR Equipped drones:** Highly suitable for generating high-resolution terrain maps and identifying topographical changes in flood-prone areas.
- **Long-endurance drones:** Ideal for continuous monitoring of large desert and coastal areas, providing prolonged surveillance capabilities.
- **Swarm drones:** Suitable for rapid response and wide-area coverage during emergencies like cyclones, enabling coordinated operations and extensive data collection.

The integration of advanced sensors, navigation systems, and real-time data capabilities into drones represents significant technological advancements. These innovations enhance precision, efficiency, and versatility in data collection, crucial for accurate risk mapping and monitoring.

1.2.4. AI **Data** Analysis

AI-driven data analysis tools are essential for predictive analytics and risk modeling, enabling the center to anticipate and prepare for potential hazards more effectively. The use of artificial intelligence represents a cutting-edge approach to data analysis, providing advanced capabilities for identifying patterns, predicting hazards, and optimizing response strategies.

Real-time data is critical for early warning services as it allows for immediate updates and swift decision-making. Integrating real-time data from various sources such as weather stations, remote sensors, Numerical Weather Prediction Models and drones enhances the accuracy and timeliness of hazard detection.

The combination of GIS platforms and AI-driven data analysis tools enables the processing of vast amounts of real-time data, allowing for sophisticated modeling and simulation of potential hazard scenarios. This integration facilitates the generation of accurate and actionable early warnings, improving the center's ability to respond promptly to emerging threats. The specific contributions of these technical solutions and equipment to Early Warning Services are as follows:

- **Predictive Analytics:** AI-driven data analysis tools can predict potential hazards by analyzing historical data and identifying patterns. This predictive capability allows the center to issue early warnings and prepare mitigation strategies.
- **Risk Modeling:** Advanced risk modeling tools use real-time data to simulate various hazard scenarios, helping to identify vulnerable areas and optimize response plans. This ensures that resources are allocated efficiently and that the most at-risk communities receive timely assistance.
- **Real-time Monitoring:** Integrating real-time data from diverse sources provides a comprehensive view of the current situation, enabling continuous monitoring of hazards. This real-time insight is crucial for making informed decisions and issuing timely warnings.
- **Optimized Response Strategies:** AI-driven analysis helps in optimizing response strategies by providing insights into the best courses of action. This includes identifying evacuation routes, deploying resources effectively, and minimizing the impact of hazards.
- The integration of GIS Modeling and Simulation Tools, Drone technologies and AI Data Analysis enables the multi-hazard early warning center in Oman to produce highly customized and actionable climate information for various sectors:
- **Agriculture:** Using GIS and real-time data from drones, the center can provide farmers with detailed forecasts on drought conditions, soil moisture levels, and optimal planting times. Thermal imaging and AI analysis can help in monitoring crop health and predicting pest outbreaks.

- **Urban Planning:** Urban planners can utilize flood risk maps, heat maps, and high-resolution terrain data from LiDAR-equipped drones to design resilient infrastructure. Real-time monitoring and predictive analytics can inform zoning laws and building codes to mitigate the impact of natural disasters.
- **Emergency Response:** Real-time data from swarm drones and VTOL drones can be used to assess damage and coordinate response efforts during emergencies. GIS dashboards and predictive models can guide emergency services to prioritize areas at highest risk.
- **Infrastructure:** Detailed inspections and monitoring of critical infrastructure such as bridges, roads, and power lines can be performed using multirotor drones. AI data analysis can predict potential failures and recommend preventative maintenance.
- **Coastal Management:** Waterproof drones and high-end GIS tools can monitor coastal erosion, sea-level rise, and potential flooding events. This information can be used to protect coastal communities and manage marine resources effectively.

1.3. Technical Solutions and Specifications for Equipment and Infrastructure for Monitoring and Warning Service

To strengthen Monitoring and Warning Service capabilities and enhance the efficiency of Oman's multi-hazard early warning center, **Table 7** outlines the proposed technical solutions, equipment specifications, and infrastructure improvements:

Table 7: Technical Solutions and Equipment Specifications for Improving Monitoring and Warning Service Capabilities

Sendai Pillar	Technology and Technical Equipment	Number	Utility for Climate Risk and Multi-Hazard Early Warning System in Oman
Monitoring and Warning Service	Creation of Non-Contacting Radar Level Gauges on the wadi crossing the urban area	50	Monitor water levels in wadis to detect and respond to potential flooding.
	X-band Radars	5	Provide high-resolution data for urban flood monitoring and fill gaps in radar networks.
	C-band Radars	4	Balance range and resolution for general weather surveillance and moderate precipitation measurement.
	S-band Radars	2	Detect severe weather and monitor tropical cyclones over long ranges.

The proposed monitoring and warning services involve a range of technologies designed to enhance weather surveillance and flood monitoring capabilities. Each component has specific technical requirements and applications, aimed at improving the accuracy, coverage, and timeliness of weather and flood-related information.

1.4. Evaluation of Technology Suitability and Innovation for strengthening Monitoring and Warning Service capabilities in the Multi-Hazard Early Warning Center in Oman

1.4.1. Non-Contacting Radar Level Gauges on the Wadi Crossing the Urban Area

The creation of 50 non-contacting radar level gauges on the wadi crossing the urban area will monitor water levels in wadis to detect and respond to potential flooding. Radar gauges will be installed at critical points along wadis, especially near urban areas prone to flooding. Non-contact radar technology will be beneficial for remote and hazardous locations, providing precise and reliable water level measurements without being affected by debris or sediment. Integration with early warning systems will be necessary to provide timely alerts to urban populations and authorities. Solar-powered or other sustainable power sources will enhance reliability, especially in remote areas. These gauges will be perfect for urban areas where traditional water level monitoring methods are impractical. The use of non-contact radar gauges represents a significant advancement in flood monitoring technology, offering high precision and minimal maintenance.

1.4.2. X-band Radars

The deployment of 5 X-band radars will provide high-resolution data for urban flood monitoring and fill gaps in radar networks. X-band radars are known for their high resolution, which is ideal for detailed monitoring of urban flood scenarios, although they have a shorter range compared to C-band and S-band radars. They will be positioned to cover urban areas with a high risk of flooding, involving placement at relatively high vantage points to avoid obstructions. These radars will be integrated into the existing meteorological network to enhance overall data granularity and reliability. Suitable for densely populated urban areas requiring detailed flood monitoring, the high-resolution capabilities of X-band radars offer enhanced urban flood monitoring, significantly improving early warning and response times.

1.4.3. C-band Radars

The deployment of 4 C-band radars will balance range and resolution for general weather surveillance and moderate precipitation measurement. C-band radars offer a good balance between range and resolution, making them suitable for medium-range weather surveillance, effectively covering broader areas compared to X-band radars. They are useful for monitoring moderate precipitation, tracking weather patterns, and providing early warnings for adverse weather conditions. Installation may require substantial infrastructure including towers and power supply, ensuring continuous and reliable operation. Suitable for general weather monitoring in medium-range applications, C-band radars provide a versatile solution for comprehensive weather surveillance by combining range and resolution.

1.4.4. S-band Radars

The deployment of 2 S-band radars will detect severe weather and monitor tropical cyclones over long ranges. S-band radars are capable of detecting severe weather phenomena such as cyclones at long distances due to their lower frequency and higher penetration through precipitation. These radars will be strategically positioned to cover coastal areas and regions prone to cyclones, ensuring early detection and warning capabilities. Data from S-band radars will be integrated with national and regional meteorological networks to provide comprehensive and timely information to authorities and the public. Ideal for coastal areas and regions vulnerable to severe weather events, the long-range detection capabilities of S-band radars enhance the ability to monitor and respond to severe weather events, improving disaster preparedness and resilience.

1.5. Technical Solutions and Specifications for Equipment and Infrastructure for Dissemination and Communication

To strengthen Monitoring and Warning Service capabilities and enhance the efficiency of Oman's multi-hazard early warning center, **Table 8** outlines Technological Enhancements and Equipment Specifications to Upgrade Dissemination and Communication Systems.

Table 8: Proposed Technological Enhancements and Equipment Specifications to Upgrade Dissemination and Communication Systems

Sendai Pillar	Technology and Technical Equipment	Number	Utility for Climate Risk and Multi-Hazard Early Warning System in Oman
Dissemination and Communication	Emergency alert systems	1 System	Deliver urgent alerts to the public efficiently.

Mass notification software	1 License each	Coordinate mass communications for timely warnings.
Mobile alert applications	1 License each	Send notifications directly to mobile devices.
Social media integration tools	1 License each	Disseminate information quickly through social media channels.
Radio and television broadcast equipment	1 System	Broadly broadcast warnings and information.
SMS and email systems	1 License each	Reach out to individuals via SMS and email alerts.
Data Analysis & Visualization with AI: AI technologies to analyze large datasets and visualize climate risks. Advanced AI tools to improve decision-making and risk forecasting for extreme weather events.	1 System	Analyze large datasets, identify climate risks, simulate scenarios, improve decision-making, and generate interactive dashboards.

The integration of diverse dissemination and communication tools, combined with Data Analysis, Visualization, and AI technologies, will create a robust, multi-channel alert system. AI-powered data analysis, risk forecasting models, and visualization platforms will enhance decision-making and risk prediction, while tools like emergency alert systems, mass notification software, mobile applications, and broadcast channels ensure efficient and wide-reaching communication. This comprehensive approach addresses Oman's unique geographic and demographic challenges, providing a resilient and data-driven emergency management system.

1.6. Evaluation of Technology Suitability and Innovation for strengthening Dissemination and Communication capabilities in the Multi-Hazard Early Warning Center in Oman

1.6.1. Emergency Alert Systems

The emergency alert system will deliver urgent alerts to the public efficiently through a centralized platform capable of broadcasting immediate warnings across various channels. This platform will integrate multiple communication technologies, including radio, television, SMS, email, and mobile applications, ensuring comprehensive coverage. Utilizing advanced data analytics and real-time monitoring, the system can rapidly assess and respond to emergencies, minimizing response times. This integration ensures that critical information reaches the public promptly, providing clear and concise instructions to maximize safety and preparedness.

The emergency alert system is particularly well-suited for Oman due to its diverse geography and population distribution. The system's ability to deliver alerts across multiple channels ensures that both urban and remote areas are covered. This is crucial for a country like Oman, where there are significant variations in population density and access to communication infrastructure. Additionally, Oman has a significant non-Omani population speaking diverse languages. The system can accommodate this diversity by delivering alerts in multiple languages, ensuring that all residents, regardless of their linguistic background, receive and understand the critical information. This feature is essential for effective communication in a multicultural society and enhances the overall emergency preparedness of the nation.

Incorporating advanced alert technologies within the system allows for seamless integration with various communication channels, thereby enhancing the reach and effectiveness of emergency notifications. The use of geolocation services and targeted messaging ensures that alerts are specific to the affected areas, improving the relevance and timeliness of the information provided. The system's multilingual capabilities are particularly innovative, allowing for automatic translation and dissemination of alerts in languages commonly spoken in Oman, such as Arabic, English, Hindi, Urdu, and others. Additionally, the system's adaptive learning capabilities can analyze previous emergencies to optimize future responses, making it a dynamic and evolving tool for disaster management. The innovative combination of these technologies ensures a robust, reliable, and efficient emergency alert system tailored to the unique needs of Oman and its diverse population.

1.6.2. Mass Notification Software

Mass notification software will coordinate mass communications for timely warnings. This software enables the automated distribution of alerts and information to a wide audience, ensuring efficient and simultaneous communication across multiple platforms such as email, SMS, social media, and mobile apps. Integrating with existing communication infrastructures, the software ensures that critical information is delivered promptly to relevant stakeholders and the general public. Its centralized management system allows for easy control and customization of messages, ensuring that alerts are clear, concise, and appropriately targeted.

The mass notification software is highly suitable for coordinating responses across Oman’s various regions, ensuring timely dissemination of information during emergencies. Given Oman’s diverse population and geographic spread, this software facilitates rapid communication to both urban and remote areas. It is especially effective in addressing the needs of the non-Omani population, who may speak different languages, by supporting multilingual notifications. This ensures that all residents, regardless of their linguistic background, receive and understand emergency alerts, enhancing overall public safety.

The software utilizes state-of-the-art communication algorithms to prioritize and distribute alerts quickly, significantly improving the overall emergency response system. Its ability to integrate with multiple communication channels ensures that messages are disseminated simultaneously, reducing delays and increasing the reach of critical information. The software’s adaptive learning capabilities analyze the effectiveness of previous notifications to optimize future alert strategies. Additionally, the software can support geo-targeted notifications, sending alerts specifically to affected regions, which enhances the relevance and impact of the messages. This innovative approach ensures that Oman’s emergency communication infrastructure is robust, responsive, and capable of addressing the unique challenges of a diverse and geographically varied population.

1.6.3. Mobile Alert Applications

Mobile alert applications will send notifications directly to mobile devices, providing a direct and immediate way to reach individuals. These applications leverage the widespread use of smartphones to disseminate critical alerts rapidly, ensuring that information is delivered in real-time. The applications can integrate with other emergency communication systems, allowing for seamless coordination and consistency in messaging. They support various notification formats, including text, images, and videos, enhancing the clarity and effectiveness of the alerts. Additionally, these applications can track user engagement, providing feedback on the reach and impact of the notifications.

Mobile alert applications are highly suitable for Oman, where mobile phone penetration is high, allowing for widespread and immediate dissemination of alerts. Given the country's diverse population, the applications can support multilingual notifications, ensuring that all residents, regardless of their language, receive and understand the alerts. The high usage of smartphones across different demographic groups in Oman makes these applications an effective tool for ensuring that critical information reaches a broad audience quickly.

The use of geolocation services within these mobile alert applications allows for the targeting of alerts to specific areas affected by emergencies. This ensures that relevant information is delivered to those who need it most, enhancing the precision and timeliness of the emergency response. The applications can dynamically adjust the alert radius based on the severity of the situation, providing a tailored approach to each emergency. Additionally, the integration of interactive features, such as two-way communication, allows users to report their status and needs, providing valuable data to emergency responders. This innovative use of technology ensures that Oman’s emergency communication system is responsive, efficient, and capable of addressing the unique challenges posed by emergencies.

1.6.4. Social Media Integration Tools

Social media integration tools will disseminate information quickly through social media channels. These tools enable the rapid spread of alerts and updates, taking advantage of the fast-paced and wide-reaching nature of social media platforms such as Facebook, Twitter, Instagram, and LinkedIn. By automating the posting process, these tools ensure that critical information is disseminated simultaneously across multiple social media accounts. They also provide real-time monitoring and analytics to track the reach and engagement of posts, allowing for adjustments to maximize the effectiveness of the communication strategy. The tools support various content formats, including text, images, and videos, ensuring that messages are clear and engaging.

Social media integration tools are perfect for Oman, where social media usage is significant among the population. These tools enable quick and widespread dissemination of information, reaching a broad audience across different demographics. In a country where many people rely on social media for news and updates, these tools ensure that critical alerts and information are delivered efficiently and effectively.

Employing advanced algorithms, social media integration tools optimize the timing and content of social media posts for maximum engagement and reach during emergencies. These algorithms analyze user behavior and platform trends to determine the best times to post and the most effective content formats. Additionally, the tools can segment audiences based on various criteria, allowing for targeted messaging that increases relevance and impact. The integration of AI-driven insights helps in crafting compelling messages that capture attention quickly, essential during emergencies when timely information dissemination is critical. This innovative approach ensures that Oman's emergency communication strategy leverages the power of social media to its fullest potential, enhancing the overall reach and engagement of emergency alerts.

1.6.5. Radio and Television Broadcast Equipment

Radio and television broadcast equipment will broadly broadcast warnings and information. This traditional media infrastructure ensures that alerts are accessible to a broad audience, including those without access to digital or mobile communication channels. The system will integrate advanced broadcasting technologies, capable of transmitting high-quality audio and visual signals over large distances. It will include features such as automated alert systems, which can interrupt regular programming to deliver emergency messages, ensuring that critical information reaches the public promptly. The system will also support the rebroadcast of alerts across multiple channels simultaneously, increasing the reach and effectiveness of the communication.

This equipment is essential for reaching all segments of Oman's population, particularly in rural and underserved areas where digital access may be limited. In these areas, radio and television remain vital sources of information, making this system crucial for comprehensive emergency communication. By ensuring that even those without smartphones or internet access receive timely warnings, the system addresses the needs of a diverse population, enhancing overall public safety and preparedness.

Modern broadcast technologies incorporated into this system allow for simultaneous multi-channel dissemination, ensuring consistent and timely delivery of emergency information. The system's capability to automate and manage alert broadcasts across various platforms, including FM/AM radio and terrestrial/satellite TV, represents a significant innovation. This multi-channel approach maximizes the reach of emergency messages, ensuring that they are delivered efficiently and effectively to the entire population. Additionally, the integration of digital broadcasting standards will improve signal clarity and reliability, further enhancing the system's effectiveness. This innovative use of traditional media, combined with modern technology, ensures a robust and comprehensive emergency communication strategy for Oman.

1.6.6. SMS and Email Systems

SMS and email systems will reach out to individuals via SMS and email alerts. These systems ensure that messages are delivered directly to recipients' phones and email accounts, providing a reliable means of communication that can complement other alert systems. The SMS system will allow for the rapid dissemination of concise alerts to a large number of recipients, ensuring immediate delivery. The email system will enable the distribution of more detailed information, including instructions, maps, and other relevant documents. Both systems will support multilingual messaging, ensuring that alerts can be understood by a diverse population. Integration with contact databases and geographic information systems will enable targeted messaging to specific areas or groups, enhancing the relevance and effectiveness of the communication.

These systems are suitable for Oman, providing a reliable and direct method of communication that can reach a broad audience, including those in remote areas. Given the widespread use of mobile phones and email in Oman, these systems will ensure that critical information is accessible to the majority of the population. They are particularly effective in reaching individuals who may not be active on social media or who live in areas with limited access to broadcast media.

The use of advanced technologies to automate and personalize messages ensures that alerts are timely and relevant. The systems can prioritize messages based on urgency and target specific groups or locations, optimizing the dissemination process. Additionally, integration with other communication platforms ensures a cohesive and coordinated approach to emergency alerts, leveraging the strengths of each system to maximize reach and impact.

1.6.7. Data Analysis & Visualization with AI

Data Analysis & Visualization with AI plays a pivotal role in strengthening the National Multi-Hazard Early Warning System by leveraging advanced technologies to analyze, predict, and visualize climate risks effectively.

1. AI-Powered Data Analysis Tools: These tools process and analyze large datasets, enabling the identification of climate risks, patterns, and trends. By transforming raw data into actionable insights, they improve situational awareness for decision-makers.
2. AI-Based Risk Forecasting Models: These models predict extreme weather events and multi-hazard risks with higher accuracy. They empower decision-makers to take proactive measures, reducing response times and mitigating potential impacts.
3. AI Visualization Platforms: : Interactive dashboards created through AI visualization platforms provide stakeholders and decision-makers with user-friendly displays of risk data. These platforms simplify complex information, facilitating quick interpretation and informed decision-making.
4. Machine Learning Algorithms: Machine learning algorithms simulate and forecast extreme weather scenarios and multi-hazard events. By learning from historical and real-time data, these algorithms enhance predictive capabilities and support long-term risk assessment strategies.

Together, these AI-driven tools enhance the accuracy, timeliness, and clarity of climate risk information. They form the foundation for a data-driven early warning system, ensuring that Oman can effectively forecast, communicate, and respond to extreme weather and multi-hazard events, ultimately safeguarding lives, infrastructure, and livelihoods.

1.7. Technical Solution for Enhancing Disaster Preparedness and Response

Enhancing disaster preparedness and response involves integrating advanced technologies, modern equipment, and effective tools to improve monitoring, evaluation, response, and recovery capabilities. The following solutions have been identified and designed to address critical needs, ensuring timely and effective disaster response and management (***Table 9***).

Table 9: Proposed Technological Enhancements and Equipment Specifications to enhance Disaster Preparedness and Response

Sendai Pillar	Technology and Technical Equipment	Number	Utility for Climate Risk and Multi-Hazard Early Warning System in Oman
Disaster Preparedness and Response	Drones with Thermal Cameras	10	Enhances search and rescue operations by identifying survivors in low-visibility conditions.
	Disaster Dashboard	1	Centralized platform for real-time monitoring, risk assessment, and decision-making.

	Training Simulators	5	Builds capacity of response teams through realistic disaster response training scenarios.
	Drill Tools	5	Enables rapid extraction of survivors from collapsed structures and debris.
	Emergency Vehicles (Ambulances)	5	Provides advanced life support and medical response to affected individuals during disasters.
	Mobile Units for Post-Disaster Evaluation	3	Facilitates rapid damage assessment and resource planning for post-disaster recovery.
	Drones for Post-Disaster Assessment	5	Conducts aerial surveys to assess infrastructure damage and disaster impact.

1.7.1. Drones with Thermal Cameras

Drones equipped with thermal cameras play a critical role in search and rescue operations during disaster events. These drones detect heat signatures of survivors in low-visibility conditions, such as nighttime, smoke, or rubble. Real-time aerial data enables quick identification of affected areas and survivors, significantly reducing response time and improving rescue efficiency. They prove especially useful during extreme events like earthquakes, floods, and fires where rapid victim location is vital.

1.7.2. Training Simulators

Training simulators provide immersive, realistic disaster scenarios to strengthen the capacity of emergency response teams. Using advanced virtual and augmented reality technologies, these systems replicate situations such as floods, earthquakes, and severe storms. Personnel gain practical skills, improve decision-making, and enhance coordination under high-pressure environments. These tools ensure response teams remain fully prepared to manage real-world disasters effectively.

1.7.3. Drill Tools

High-powered drill tools support search and rescue efforts in post-disaster operations, particularly in environments with collapsed structures or debris. These tools enable the rapid extraction of survivors trapped under rubble caused by earthquakes, landslides, or explosions. Their portability and precision allow rescue teams to access survivors quickly, reducing delays and increasing survival rates. Drill tools serve as essential equipment for effective disaster response.

1.7.4. Emergency Vehicles (Ambulances)

Advanced ambulances equipped with life-support systems provide immediate medical care and safe transport for injured individuals during disaster situations. Equipped with ventilators, defibrillators, stretchers, and oxygen systems, these vehicles ensure patients receive critical care while en route to healthcare facilities. Emergency vehicles significantly improve survival rates and reduce injury-related fatalities during crises.

1.7.5. Mobile Units for Post-Disaster Evaluation

Mobile units for post-disaster evaluation enable rapid on-site assessments to determine damage extent and priority needs. Equipped with geographic information systems (GIS), communication tools, and data analysis equipment, these units quickly reach disaster-affected zones to collect critical information. Insights from these assessments guide effective decision-making and resource allocation during recovery efforts, ensuring swift restoration of essential services.

1.7.6. Disaster Dashboard

The disaster dashboard acts as a centralized platform for real-time monitoring, analysis, and coordination of disaster management activities. Integrating risk mapping, predictive analytics, and situational awareness tools, the dashboard supports informed decision-making and improved response planning. Enhanced communication and resource tracking ensure better coordination among stakeholders, optimizing the overall effectiveness of Oman's Multi-Hazard Early Warning System.

1.7.7. Drones for Post-Disaster Assessment

Post-disaster assessment drones capture high-resolution aerial imagery and data to evaluate infrastructure damage, environmental impacts, and resource requirements. These drones deliver rapid and accurate assessments, reducing reliance on manual ground surveys and lowering evaluation costs. Efficient mapping of affected zones allows planners to prioritize recovery activities and streamline resource deployment, enhancing overall disaster recovery efficiency.

2. Environmental, Economic, and Social Assessments

2.1. Evaluation of Potential Environmental Effects from Proposed **Risk Knowledge** Equipment and Infrastructure

2.1. Geographic Information Systems Platform

The Geographic Information Systems Platform, including the ArcGIS (28 software), will have no impact on air and water quality or biodiversity and ecosystems, as it is entirely software-based and involves digital mapping and data analysis.

2.2. High-performance workstations

The high-performance workstations, will have no impact on air quality. The minimal impact of e-waste will be mitigated through certified recycling programs. Utilizing energy-efficient workstations and proper electronic waste disposal protocols will ensure that the environmental footprint is minimized.

2.2. Evaluation of Potential Environmental Effects from Proposed Monitoring and Warning Service Equipment and Infrastructure

2.2.2. Non-Contacting Radar Level Gauges on the wadi crossing the urban area

The installation of 200 non-contacting radar level gauges on wadis crossing urban areas will have no impact on water quality or ecosystems. These gauges are non-contacting and do not interfere with water bodies. Non-invasive installation techniques and regular maintenance will ensure that there are no adverse effects on local ecosystems.

2.2.3. Radars (X-band, C-band, S-band)

The deployment of X-band, C-band, and S-band radars will have no impact on air quality or biodiversity. These radars are designed to operate without interfering with wildlife. The use of energy-efficient radar systems and conducting wildlife impact assessments will ensure that these installations remain environmentally benign.

2.3. Evaluation of Potential Environmental Effects from Proposed Dissemination and Communication Equipment and Infrastructure

2.3.1. Emergency alert systems

The emergency alert systems, will have no impact on air and water quality. Proper disposal protocols for electronic components will mitigate any potential e-waste impact. Implementing upgrades rather than complete replacements where possible will further reduce any environmental footprint.

2.3.2. Mass notification software, Mobile alert applications, Social media integration tools, SMS and email systems

Mass notification software, mobile alert applications, social media integration tools, and SMS and email systems will have no impact on air and water quality, as they are software-based solutions. There will be no significant impact from e-waste due to the minimal physical infrastructure required. Using cloud-based solutions will continue to minimize the need for additional hardware.

2.4. Evaluation of Potential Environmental Effects from Proposed Equipment Specifications to Enhance Disaster Preparedness and Response

The proposed equipment specifications to enhance disaster preparedness and response have been carefully assessed, and no significant environmental impacts are anticipated. All technologies, including drones, training simulators, emergency vehicles, and mobile units, are designed with modern, environmentally friendly features that comply with international standards. Proper operational protocols and maintenance practices will ensure minimal resource consumption and waste generation. As a result, the deployment and use of this equipment pose no adverse environmental effects

2.5. Social Impact Assessment and Stakeholder Considerations

The implementation of the multi-hazard early warning system in Oman aims to enhance disaster preparedness and response capabilities. Conducting a comprehensive social impact assessment is essential to understand the potential effects on local communities and stakeholders, ensuring that the system is socially inclusive and beneficial. This assessment will focus on various aspects of public life and stakeholder engagement to maximize the system's effectiveness and acceptance.

2.5.1. Social Impact Assessment

2.5.1.1. Public Safety and Well-being

The early warning system is expected to significantly improve public safety by providing timely alerts and information during emergencies, thereby reducing the risk of injury and loss of life. Effective early warnings can lead to quicker evacuations, better-prepared communities, and overall reduced casualties and damage. The system will ensure that the alerts are accessible to all segments of the population, including vulnerable groups such as the elderly, disabled, and non-Omani residents. This involves:

- **Multilingual Alerts:** Providing alerts in multiple languages, including Arabic, English, Hindi, Urdu, and others spoken by expatriates.
- **Inclusive Communication:** Using various communication channels (e.g., SMS, email, social media, radio, and TV) to reach different demographic groups.
- **Accessibility Features:** Ensuring that alerts are accessible to individuals with disabilities, such as offering audio alerts for the visually impaired and visual alerts for the hearing impaired.

- **Climate Services:** Offering planners and the private sector critical information to anticipate and respond to climate risks, thereby enhancing public safety.

2.5.1.2. Community Resilience

The system will enhance community resilience by enabling better preparation and response to natural hazards. This includes educating the public on emergency procedures, building a culture of preparedness, and fostering community networks that support each other during crises. Engaging with community leaders, local organizations, and schools to disseminate information and build trust in the system. Activities may include:

- **Workshops and Drills:** Conducting regular training workshops and emergency drills to ensure the community is familiar with response procedures.
- **Educational Campaigns:** Running campaigns in schools, community centers, and through media to raise awareness about disaster preparedness.
- **Community Networks:** Encouraging the formation of local response teams that can act as first responders and support vulnerable individuals during emergencies.
- **Climate Services:** Providing planners with data and forecasts to integrate climate resilience into community planning and infrastructure projects, enhancing overall resilience.

2.5.1.3. Economic Stability

Mitigating the effects of natural disasters, the system will contribute to economic stability by preventing damage to infrastructure, businesses, and homes. This will reduce recovery costs, minimize business interruptions, and protect livelihoods. Ensuring that small businesses and low-income households are aware of and can benefit from the early warning system. Measures include:

- **Business Continuity Planning:** Offering resources and support to businesses for developing continuity plans.
- **Financial Support Programs:** Providing financial assistance or incentives for households and businesses to invest in disaster preparedness measures.
- **Insurance Awareness:** Promoting awareness of and access to insurance products that can help mitigate economic losses.
- **Climate Services:** Equipping the private sector with climate data and tools to anticipate risks, optimize operations, and protect assets, thereby ensuring economic resilience.

2.5.1.4. Social Cohesion

The system can foster social cohesion by encouraging collective action and community support during emergencies. Shared experiences and mutual aid can strengthen community bonds and trust. Promoting inclusive participation in disaster preparedness activities and ensuring equitable access to resources and information. Strategies include:

- **Inclusive Engagement:** Involving all community members, including marginalized groups, in preparedness activities and decision-making processes.
- **Resource Allocation:** Ensuring fair and transparent distribution of resources and support during and after disasters.
- **Community Events:** Organizing events and activities that bring people together to discuss and prepare for potential hazards.
- **Climate Services:** Facilitating collaboration between planners, businesses, and the community to develop integrated strategies for disaster preparedness and resilience.

2.5.1.5. Cultural Sensitivity

The system must respect and incorporate local cultural practices and languages to be effective and widely accepted. Cultural sensitivity is crucial for the system's success and acceptance. Providing multilingual alerts and culturally appropriate communication strategies to reach diverse community members. Steps include:

- **Cultural Training:** Training emergency response personnel on local customs and practices.
- **Customized Messaging:** Crafting emergency messages that resonate with cultural values and practices.
- **Community Leaders:** Collaborating with cultural and religious leaders to disseminate information and encourage community participation.
- **Climate Services:** Ensuring that climate information and services are tailored to the cultural context and needs of local communities, making them more relevant and actionable.

2.5.2. Stakeholder Considerations

2.5.2.1. Government Agencies

Key stakeholders in the implementation and management of the early warning system. They are responsible for policy-making, coordination, and resource allocation. Ensuring inter-agency collaboration and clear communication channels to streamline emergency response efforts. Actions include:

- **Integrated Frameworks:** Developing frameworks for coordinated action among various governmental agencies.
- **Capacity Building:** Providing training and resources to government staff to effectively use the early warning system.
- **Regular Updates:** Maintaining regular updates and communication among agencies to ensure preparedness.

2.5.2.2. Local Communities

The primary beneficiaries of the early warning system. Their cooperation and trust are crucial for the system's success.

- **Considerations:** Involving community members in the planning and testing phases, and providing ongoing education and training. Engagement strategies include:
- **Community Feedback:** Establishing channels for community feedback and suggestions to improve the system.
- **Local Champions:** Identifying and empowering community champions who can advocate for preparedness and response initiatives.
- **Participatory Planning:** Involving communities in the planning and decision-making processes to ensure the system meets their needs.

2.5.2.3. Women Associations

Women play a crucial role in the effectiveness and sustainability of the early warning system. Their active involvement ensures the system is inclusive and equitable.

- **Considerations**: Recognizing and addressing the unique needs and perspectives of women in the context of early warning systems. Engagement strategies include:
- **Women's Organizations**: Collaborating with women's organizations to disseminate information and gather feedback.
- **Capacity Building**: Providing tailored education and training programs for women to enhance their understanding and ability to respond to early warnings.
- **Leadership Development**: Encouraging and supporting women to take on leadership roles within their communities related to early warning and disaster response.
- **Inclusive Communication**: Ensuring communication materials and strategies are accessible and relevant to women, considering factors such as literacy levels and preferred communication channels.

- **Gender-Sensitive Planning**: Integrating gender perspectives into the planning and implementation phases of the early warning system, ensuring that women's specific vulnerabilities and strengths are addressed.

2.5.2.4. Non-Governmental Organizations (NGOs)

NGOs can assist in outreach, education, and resource distribution, particularly in underserved areas. Partnering with NGOs to leverage their local knowledge and networks for more effective community engagement. Collaboration strategies include:

- **Joint Programs:** Developing joint programs with NGOs for community education and resource distribution.
- **Information Sharing:** Establishing mechanisms for sharing information and resources between NGOs and government agencies.
- **Targeted Outreach:** Using NGOs' reach to ensure that vulnerable and marginalized groups are included in preparedness efforts.

2.5.2.5. Private Sector

Businesses and industries that can be affected by natural hazards and have resources that can support emergency response. Engaging the private sector in disaster preparedness initiatives and encouraging corporate social responsibility activities. Initiatives include:

- **Public-Private Partnerships**: Forming partnerships to leverage private sector resources for public preparedness.
- **Employee Training**: Encouraging businesses to train their employees on emergency response and preparedness.
- **Resource Contribution**: Inviting businesses to contribute resources such as technology, expertise, and funding to support the early warning system.
- **Climate Information Services**: Promoting the use of climate information services by businesses to protect their assets and make them climate-proof. This includes:
  - **Risk Assessment**: Utilizing climate data to assess potential risks to business operations and infrastructure.
  - **Adaptation Strategies**: Implementing strategies to adapt business practices and infrastructure to mitigate the impacts of climate change.
  - **Investment in Resilience**: Encouraging investments in resilient infrastructure and technologies to reduce vulnerability to natural hazards.
  - **Corporate Social Responsibility**: Highlighting the role of corporate social responsibility in contributing to community resilience and supporting early warning systems.
- **Contribution to Oman National Emergency Fund:** Encouraging businesses to contribute financially to the Oman National Emergency Fund to support disaster preparedness, response, and recovery efforts. This includes:
  - **Donations and Pledges:** Facilitating mechanisms for businesses to make financial contributions and pledges.
  - **Fundraising Campaigns:** Organizing fundraising campaigns and events to increase private sector contributions to the fund.
  - **Transparency and Accountability**: Ensuring that contributions are used effectively and transparently to enhance disaster resilience and response capabilities.

.5.2.6. International Organizations

Provide technical expertise, and support for the development and implementation of the early warning system. Key organizations include the World Meteorological Organization (WMO) and the International Federation of Red Cross and Red Crescent Societies. Aligning the project with international best practices and leveraging global resources for capacity building. Strategies include:

- **Technical Assistance:** Seeking technical assistance from international organizations to enhance system capabilities.
- **Knowledge Exchange:** Participating in global forums and networks to exchange knowledge and best practices.

2.6. Economic Assessment of Benefits and Costs

2.6.1. Economic Benefits

2.6.1.1. Reduced Disaster Losses

The enhanced early warning system will significantly reduce economic losses caused by accelerated pace of global warming by providing timely alerts and enabling proactive measures. This system will help mitigate the devastating impacts of natural hazards such as cyclones and flash floods, which can cause extensive damage to infrastructure, housing, and public services.

Preventing damage to critical infrastructure (e.g., roads, bridges, hospitals) and residential and commercial buildings will result in substantial savings in repair and reconstruction costs. Avoiding such damage, communities can also prevent long-term economic disruptions.

The integration of climate information services into early warning systems amplifies their effectiveness by enabling comprehensive planning for climate resilience across various sectors. This integration ensures that critical data and forecasts are readily available to inform the design of infrastructure and the implementation of policies aimed at mitigating the long-term impacts of climate change. The benefits of this integration are manifold:

- **Urban Development and Infrastructure Planning:**
  - **Flooding Maps:** In Oman, the availability of precise flooding maps can guide urban development efforts. By identifying high-risk flood zones, planners can avoid construction in vulnerable areas, thereby ensuring the development of safer and more resilient infrastructure.
  - **Heatwave Forecasting:** Accurate forecasting of heatwaves allows for the optimization of power generation and distribution. This proactive measure helps reduce power shutdowns and ensures a continuous electricity supply during extreme temperature events, mitigating the adverse effects on both the economy and public health.
- **Agriculture and Water Management:**
  - **Drought Prediction:** Advanced warning of drought conditions enables farmers to implement water-saving measures and adjust planting schedules, thereby minimizing crop losses and ensuring food security.
  - **Water Resource Management:** Accurate climate data supports efficient water resource management, ensuring sustainable usage and reducing the risk of water scarcity during prolonged dry periods.
- **Disaster Preparedness and Response:**
  - **Cyclone Forecasting:** Precise forecasting of tropical cyclones' landfall optimizes evacuation efforts, reducing casualties and economic losses. Early warnings allow communities to prepare adequately, securing homes and businesses and ensuring that emergency services are ready to respond effectively.
  - **Flood Warnings:** Early warnings of imminent flooding provide crucial time for communities to evacuate and for emergency services to mobilize resources, reducing the loss of life and property.

Oman has experienced an increase in the frequency and severity of severe cyclones over the past 20 years, showcasing the country's high vulnerability and the limitations of its current early warning system. Notable cyclones include Tropical Cyclone ARB 01 in 2002 ($25 million in damages), Cyclone Gonu in 2007 (estimated $4.5 billion in damages), Tropical Cyclone Phet in 2010 ($780 million in damages), Tropical Cyclone Chapala in 2015 (costs not reported for Oman), Cyclone Mekunu in 2018 (about $1.5 billion in damages), Tropical Cyclone Luban in 2018 (Cost not reported for Oman), Tropical Cyclone Hikaa in 2019 (costs not reported), and Tropical Cyclone Shaheen in 2021 ($500 million allocated in the 2022 budget for repairs). Implementing an enhanced multi-hazard early warning system could significantly reduce such losses by ensuring timely evacuations and preparations. This improvement would facilitate better preparation and response strategies, dramatically reducing the costs and scale of damages associated with these events by improving overall preparedness and response capabilities.

2.6.1.2. Improved Business Continuity

Businesses will benefit from the system by receiving early warnings that allow them to implement continuity plans, thereby protecting their operations and assets. Effective early warning systems enable businesses to safeguard their supply chains, inventory, and critical operations, ensuring minimal disruption during and after a disaster. Minimizing business interruptions helps maintain productivity and revenue streams, reducing potential losses. Small businesses, which are particularly vulnerable to disaster-induced disruptions, will benefit from reduced downtime and faster recovery.

A study by the World Bank suggests that effective early warning systems can reduce business interruption losses by up to 30%[48]. For Oman's industrial sectors, this could translate to millions in savings annually. For Examples, In the industrial zones of Sohar and Duqm, early warnings can prevent substantial losses in manufacturing and shipping operations, ensuring continuous economic activity. For instance, timely warnings about severe weather can allow factories to secure machinery and stock, reducing damage and operational downtime.

2.6.1.3. Lower Insurance Premiums

With an effective early warning system in place, insurance companies may offer lower premiums due to the reduced risk of severe damage and claims. This reduction reflects the lower likelihood of catastrophic losses, which benefits both insurers and insured parties. Homeowners and businesses can save on insurance costs, making disaster preparedness more affordable and incentivizing wider participation. Reduced premiums also encourage greater investment in disaster-prone areas, fostering economic development. Lower insurance premiums by 15-20% for properties in high-risk areas can result in significant annual savings. For instance, if the annual insurance cost for a commercial property is $10,000, a 20% reduction would save $2,000 per year.

For example, Insurance premiums for properties in high-risk areas like Al Batinah could be significantly lowered, making insurance more accessible and encouraging more people to insure their properties. For example, businesses in coastal regions could see a reduction in insurance costs by up to 20% due to the decreased risk from improved early warning systems.

2.6.1.4. Economic Stability and Growth

The early warning system will contribute to overall economic stability by reducing the frequency and severity of disaster-related disruptions. Stable economies are better positioned to attract and retain investment, fostering long-term growth and development. A stable economic environment encourages investment, fostering economic growth and resilience. Long-term economic planning will benefit from reduced uncertainty and risk, allowing for more effective resource allocation and development strategies. Enhanced economic stability can attract foreign direct investment (FDI). A 10% increase in FDI can lead to substantial economic growth, potentially adding millions to the national GDP annually. For example, The Port of Salalah, a crucial economic hub, can maintain operations and reduce downtime during adverse weather conditions, thereby supporting economic stability and growth. The ability to predict and prepare for severe weather can help the port minimize disruptions to shipping and logistics, maintaining its status as a key regional trade hub.

2.6.2. Economic Costs

2.6.2.1. Initial Investment

The initial cost of implementing the early warning system includes purchasing equipment, developing software, and setting up communication infrastructure. This comprehensive setup is crucial for ensuring the system's efficacy and

[48] World Bank. (2013). Building Resilience: Integrating Climate and Disaster Risk into Development. *World Bank Group*.

reliability. The total budget for the project is $35 million, with $22 million requested from the Green Climate Fund and $13 million from the government as co-financing.

For example, enhancing the early warning system in Oman, considering its diverse geographical challenges, will require significant investment to cover the wide range of needs, with a total budget of $35 million [$22 million from GCF and $13 million from the government]. This includes the cost of high-performance computing systems, advanced radar networks, and comprehensive communication infrastructure.

2.6.2.2. Maintenance and Operation

Ongoing costs will include maintaining and operating the system, training personnel, and updating technology. Regular maintenance ensures the system's reliability and longevity, while operational costs cover day-to-day activities and personnel management. The annual maintenance and operation costs for Oman's system are approximately $15 million, which will be covered by the government budget. These costs ensure the continuous and effective functioning of the early warning system, supporting infrastructure, technology upgrades, and the operational needs of personnel. This budget covers the costs of regular system checks, software updates, and salaries for operational staff.

2.6.2.3. Training and Capacity Building

Investing in training programs for government staff, first responders, and community leaders to effectively use the early warning system. Capacity-building initiatives are critical for ensuring that all stakeholders are proficient in utilizing the system and responding to emergencies. Continuous training and capacity-building initiatives will require dedicated resources to keep all stakeholders proficient and ready to respond. Training costs in Oman can be estimated at $1 million to $2 million annually, covering workshops, drills, and educational materials. This includes regular training sessions, simulation exercises, and workshops to keep all personnel up-to-date with the latest protocols and technologies.

2.6.2.4. Public Awareness and Education

Conducting public awareness campaigns and educational programs to ensure widespread understanding and acceptance of the system. Effective communication and education strategies are essential for fostering public trust and encouraging proactive behaviour during emergencies. Allocating funds for ongoing outreach and education efforts is crucial for community engagement and effective system utilization. Public awareness campaigns may cost around $500,000 to $1 million annually, including media advertisements, community workshops, and educational materials. These campaigns aim to educate the public about the early warning system, the types of alerts they may receive, and the actions they should take in response to different types of warnings.

2.6.3. Long-Term Economic Benefits and Global Implications

Investing in early warning systems yields substantial cost savings through reduced disaster damage and quicker recovery times, far outweighing the initial and ongoing expenses. Effective early warning systems play a crucial role in significantly reducing both economic and human costs associated with natural disasters, ultimately providing substantial long-term economic benefits. Numerous studies have demonstrated that such investments can yield impressive returns, often saving multiple times the initial investment in avoided losses. For instance, the United Nations estimates that every dollar spent on disaster risk reduction translates into approximately $7 in disaster recovery cost savings[49].

The macroeconomic benefits include national economic stability, as early warning systems prevent extensive damage to infrastructure and agriculture, ensuring minimal disruption to economic activities. This stability fosters investor confidence and promotes sustainable economic growth. Additionally, reducing the impact of natural disasters minimizes casualties and injuries, decreasing healthcare costs and maintaining workforce productivity. Investments in resilient infrastructure, guided by early warning data, result in long-term savings by avoiding repeated reconstruction costs, while enhancing global competitiveness by making countries with robust disaster risk management systems more attractive to international businesses and investors.

[49] UNISDR. (2015). Global Assessment Report on Disaster Risk Reduction. *United Nations Office for Disaster Risk Reduction.*

On the microeconomic level, early warnings enable local communities to take preventive measures, safeguarding homes, businesses, and livelihoods, thus reducing individual and household economic losses. Local businesses benefit from fewer interruptions and quicker recovery times, ensuring sustained operations and economic stability. Accurate forecasts allow property owners to secure assets and minimize damage, leading to lower repair costs and insurance premiums. Precise climate data also supports efficient resource management, such as water and energy conservation during droughts or heatwaves, translating into cost savings and resource sustainability for households and small businesses.

The long-term benefits of investing in early warning systems extend beyond immediate cost savings. These systems contribute to the development of resilient communities capable of withstanding and recovering from climate-related events. Moreover, the knowledge and technology gained from implementing such systems in one region can be replicated globally, enhancing resilience on a broader scale. In Oman, for example, the precise mapping of flood zones not only aids in local urban planning but also serves as a model for other regions facing similar challenges. The ability to forecast heatwaves and optimize power generation can be adapted to different climates and energy infrastructures worldwide. By sharing best practices and technological advancements, countries can collectively improve their resilience to climate change.

In conclusion, the integration of early warning systems into disaster risk management provides macro and microeconomic benefits that significantly enhance resilience and sustainability. These systems safeguard national economies and public health, empowering local communities and businesses to withstand and recover from disasters. The global replication of these systems further amplifies their value, contributing to worldwide efforts to combat the adverse effects of climate change.

2.6.4. Financing Mechanism

2.6.4.1. Financing Mechanisms and Potential Sources

The financing for the National Multi-Hazard Early Warning System (NMHEWS) project totals $35 million USD. This budget will be secured through a combination of international and domestic funding sources:

- **Green Climate Fund (GCF):** The GCF will provide $22 million USD, which will cover a significant portion of the capital expenditures (Capex) required for the development and deployment of the early warning system infrastructure, technology acquisition, and initial capacity-building efforts.
- **Government of Oman:** The Government of Oman will contribute $13 million USD to the project, which will also be allocated to capital expenditures (Capex). This funding will complement the GCF funding in areas such as infrastructure development, technology acquisition, and other essential investments. The operation costs for the NMHEWS are already covered by the Government of Oman, with an annual average expenditure of $30-35 million USD, ensuring the sustainability of the system's ongoing operations.
- **Private Sector Investment:** While the primary funding sources are GCF and the Government of Oman, the project will also explore opportunities for private sector involvement, particularly in the areas of technology deployment and infrastructure maintenance. Potential private sector partners may include technology firms, telecommunications companies, and infrastructure developers.

2.6.4.2. Detailed Description of Capital Expenditures (Capex) and Operational Expenditures (Opex) Including Operations and Maintenance (O&M)

Capital Expenditures (Capex): The Capex for the NMHEWS project, supported by the combined contributions of the GCF and the Government of Oman, includes the costs associated with the development and deployment of the early warning system infrastructure. This encompasses the procurement of advanced meteorological equipment, installation of monitoring stations, development of data processing and analysis platforms, and initial training and capacity-building activities.

- **Infrastructure Development:** This includes the construction of new monitoring stations, upgrading existing facilities, and establishing data centers.
- **Technology Acquisition:** Procurement of high-performance computing systems, AI-powered data analysis tools, GIS platforms, and other essential technologies.

- **Capacity Building:** Initial training programs for government officials, technical staff, and community leaders to ensure the effective use of the NMHEWS.

Element	Technology and Technical Equipment	Number	Estimated Cost per Unit (USD)	Total Cost (USD)
Risk Knowledge	Geographic Information Systems (GIS) Platform: ArcGIS Suite (1 License for 28 software)	1 License	100,000	100,000
	Computers: High-performance workstations	10	5,000	50,000
	Fixed-wing drones	5	10,000	50,000
	Multirotor drones	8	5,000	40,000
	VTOL drones	2	20,000	40,000
	Waterproof/Amphibious drones	3	10,000	30,000
	Thermal Imaging Equipped drones	4	15,000	60,000
	LiDAR Equipped drones	1	50,000	50,000
	Long-endurance drones	2	30,000	60,000
	Swarm Drones (sets of 5-10 drones each)	1 set	50,000	50,000
	AI data analysis	1 License	50,000	50,000
	Modeling and simulation tools	1 License	100,000	100,000
Monitoring and Warning Service	Creation of Non-Contacting Radar Level Gauges on the wadi crossing the urban area	50	20,000	1,000,000
	X-band Radars	5	200,000	1,000,000
	C-band Radars	4	500,000	2,000,000
	S-band Radars	2	700,000	1,400,000
Dissemination and Communication	Emergency alert systems	1 System	200,000	200,000
	Mass notification software	1 License	50,000	50,000
	Mobile alert applications	1 License	25,000	25,000
	Social media integration tools	1 License	25,000	25,000
	Radio and television broadcast equipment	1 System	100,000	100,000
	SMS and email systems	1 License	50,000	50,000
	Data Analysis & Visualization with AI	1 System	2,000,000	2,000,000
Disaster Preparedness and Response	Drones with Thermal Cameras	10	10,000	100,000
	Disaster Dashboard	1	2,000,000	2,000,000
	Training Simulators	5	50,000	250,000
	Drill Tools	5	50,000	250,000
	Emergency Vehicles (Ambulances)	5	200,000	1,000,000
	Mobile Units for Post-Disaster Evaluation	3	200,000	600,000
	Drones for Post-Disaster Assessment	5	20,000	100,000

Operational Expenditures (Opex): The Opex for the NMHEWS, including operations and maintenance (O&M), is currently covered by the Government of Oman, with an annual average expenditure of $30-35 million USD. This ongoing commitment ensures the sustainability of the system and includes:

- **Operations and Maintenance (O&M):** O&M costs include regular maintenance of monitoring stations, software updates for data processing systems, replacement of outdated equipment, and ongoing training for staff. The sustainability of the system is heavily dependent on a well-funded O&M budget to ensure uninterrupted service delivery.
- **Administrative Costs:** These include the costs associated with project management, including staff salaries, office supplies, utilities, and other operational expenses necessary for the day-to-day functioning of the NMHEWS.

2.6.5. Economic and Financial Viability

2.6.5.1. Projections of Economic and Financial Outcomes

The NMHEWS project is projected to deliver significant economic and financial benefits, driven by the reduction of economic losses from natural disasters through timely early warnings and enhanced preparedness:

- **Reduced Economic Losses:** The NMHEWS will help minimize economic losses associated with natural disasters, such as infrastructure damage, business interruptions, and agricultural losses, potentially saving millions of dollars in avoided damages.
- **Increased Investment in Resilience:** The system is anticipated to attract further investment in climate-resilient infrastructure and technologies, both from the government and the private sector, thereby enhancing the overall economic resilience of Oman.
- **Improved Public Safety and Productivity:** Enhanced early warning capabilities are expected to improve public safety, reduce injury and loss of life, and maintain productivity levels during adverse weather events.

2.6.5.2. Comprehensive Cost-Benefit Analysis

A comprehensive cost-benefit analysis (CBA) has been conducted to assess the economic viability of the NMHEWS project. The analysis includes:

- **Cost Assessment:** The total costs of the project, including Capex, Opex, and O&M, have been calculated and compared against the expected economic benefits. This includes both direct benefits (e.g., reduced disaster response costs) and indirect benefits (e.g., enhanced business continuity, improved investor confidence).
- **Benefit Assessment:** The benefits considered include avoided damages and losses from natural disasters, savings in emergency response costs, and long-term economic gains from improved resilience and preparedness. The analysis also considers the value of lives saved and the reduction in health care costs associated with disaster-related injuries and fatalities.
- **Net Present Value (NPV) and Internal Rate of Return (IRR):** The CBA results indicate a positive NPV and an IRR that exceeds the project's cost of capital, demonstrating that the NMHEWS project is financially viable and offers substantial economic returns relative to its costs.
- **Sensitivity Analysis:** The analysis includes sensitivity testing to account for potential variations in key assumptions, such as changes in disaster frequency, cost overruns, and variations in economic growth rates. The results confirm the robustness of the project's economic and financial viability under various scenarios.

These sections outline the financial and economic foundations of the NMHEWS project, demonstrating its potential to deliver significant benefits to Oman while ensuring financial sustainability and resilience against future climate-related challenges.

2.6.6. Exit Strategy and Sustainability

2.6.6.1. Plan for Long-Term Sustainability

Ensuring the long-term sustainability of the early warning system is critical for its continued success and impact. The plan includes several key components:

1. **Institutional Integration**:
    - **Governmental Support**: Embedding the early warning system within national and local government frameworks ensures continuous support. This involves aligning the system with national disaster risk reduction strategies, climate change adaptation plans, and development goals.
    - **Policy Frameworks**: Advocating for and establishing policies that mandate the operation and maintenance of the early warning system within governmental agendas. This includes legislation that supports funding allocation and institutional responsibilities.
2. **Capacity Building**:
    - **Training Programs**: Implementing ongoing training programs for local communities, government officials, and other stakeholders. These programs focus on system operation, maintenance, and data interpretation to ensure local ownership and technical proficiency.
    - **Knowledge Transfer**: Developing and disseminating educational materials, manuals, and online resources to facilitate continuous learning and skill development among stakeholders.
3. **Financial Mechanisms**:

- **Sustainable Funding Models**: Establishing a mix of funding sources, including government budgets, private sector investments, and international aid. Creating endowment funds or dedicated financial reserves to cover unforeseen expenses and maintenance costs.
- **Public-Private Partnerships**: Engaging the private sector through partnerships that provide financial support, technology, and expertise. Encouraging corporate social responsibility initiatives that contribute to the system's sustainability.

4. **Technology and Infrastructure**:
   - **Durable Equipment**: Investing in high-quality, durable technology and infrastructure that require minimal maintenance. Regularly updating and upgrading the technology to keep pace with advancements and emerging threats.
   - **Maintenance Protocols**: Establishing comprehensive maintenance schedules and protocols to ensure the continuous operation of the system. Training local technicians to handle routine maintenance and troubleshooting.
5. **Community Engagement**:
   - **Active Participation**: Involving community members in ongoing monitoring, feedback, and improvement processes. This ensures the system remains relevant and effective in addressing local needs and vulnerabilities.
   - **Education and Awareness**: Conducting regular awareness campaigns and educational programs to keep the community informed and engaged with the early warning system.

2.6.6.2. Strategies to Ensure Project Continuity After Initial Funding

To guarantee the project's continuity beyond the initial funding period, several strategies will be implemented:

1. **Diversified Funding Sources**:
   - **Multiple Revenue Streams**: Securing funding from various sources such as international grants, national budgets, and private sector investments.
   - **Consultancy Services for the Private Sector:** Providing paid tailored climate risk data and early warning information to businesses, enabling them to make informed decisions and safeguard their operations.
2. **Partnership Development**:
   - **Strategic Alliances**: Building alliances with international organizations, NGOs, academic institutions, and private sector entities. These partnerships provide financial resources, technical expertise, and advocacy support.
   - **Collaborative Projects**: Developing joint projects and initiatives with partners to enhance the system's capabilities and reach. This includes research collaborations, technology development, and capacity-building programs.
3. **Revenue-Generating Activities**:
   - **Service Provision**: Offering consultancy services, training programs, and technical support to other regions and sectors. Generating income by providing specialized services that leverage the expertise and infrastructure of the early warning system.
   - **Commercial Applications**: Identifying commercial applications of the system's technology and data. This could include licensing agreements, data sales, and collaborations with technology firms.
4. **Policy Advocacy**:
   - **Legislative Support**: Advocating for laws and regulations that support the early warning system's operation and funding. This includes integrating the system into national disaster management plans and securing legislative backing for sustained financial support.
   - **Incentive Programs**: Promoting policies that incentivize private sector investment and participation in the early warning system. This could include tax breaks, subsidies, and recognition programs for contributing businesses.
5. **Monitoring and Evaluation**:
   - **Performance Metrics**: Establishing clear performance metrics and indicators to assess the system's effectiveness and impact. Regularly collecting and analyzing data to identify strengths, weaknesses, and areas for improvement.
   - **Feedback Mechanisms**: Creating robust feedback mechanisms to gather input from stakeholders and communities. Using this feedback to refine and enhance the system's operations and strategies.
6. **Local Ownership and Responsibility**:

    - **Empowerment Programs**: Empowering local authorities and community leaders to take ownership of the system. Providing them with the necessary tools, training, and authority to manage and sustain the system.
    - **Community-Led Initiatives**: Encouraging community-led initiatives and solutions that complement the early warning system. Supporting grassroots efforts to build resilience and enhance local disaster preparedness.
7. **Scaling and Replication**:
    - **Replication Models**: Developing models and best practices for replicating the early warning system in other regions and countries. Sharing knowledge, tools, and experiences to facilitate wider adoption.
    - **Scaling Up**: Planning for the gradual scaling up of the system to cover more areas and address additional hazards. Ensuring that the system remains adaptable and scalable to meet evolving needs and challenges.

Implementing these comprehensive strategies, the project aims to secure its long-term sustainability and ensure that the early warning system continues to provide critical services to communities, safeguarding lives and assets well into the future.

Chapter 3: Detailed Project Information

1. Climate Rationale

1.1. Justification of the Project's Climate Benefits

Oman faces significant climate risks, including extreme weather events such as cyclones, floods, and heatwaves, exacerbated by climate change. Coastal areas and expanding urban regions are particularly vulnerable, with potential impacts on infrastructure, livelihoods, and overall economic stability. The project aims to enhance Oman's resilience to these climate-related hazards through improved climate information services and early warning systems, addressing the critical need for timely and accurate climate risk data.

Historically, Oman has suffered severe impacts from tropical cyclones and heat waves, highlighting the urgent need for enhanced early warning systems and climate resilience. Between 2002 and 2021, Oman was hit by multiple severe tropical cyclones, leading to significant infrastructure damage and economic losses estimated at $7.30 billion USD. Major cyclones and their associated damages include:

- **Tropical Cyclone ARB 01 (2002)**: Caused $25 million USD in damages.
- **Cyclone Gonu (2007)**: Caused $4.5 billion USD in damages and resulted in at least 59 lives lost.
- **Cyclone Phet (2010)**: Caused $780 million USD in damages and 24 lives lost.
- **Cyclone Chapala (2015)**: Contributed to infrastructure and economic impacts.
- **Cyclone Mekunu (2018)**: Caused around $1.5 billion USD in damages and at least 30 lives lost.
- **Cyclone Luban (2018)**: Caused flooding and damage to property and infrastructure.
- **Cyclone Hikaa (2019)**: Resulted in significant but unreported financial impacts.
- **Cyclone Shaheen (2021)**: Caused severe flooding and infrastructure damage estimated at $500 million USD and resulted in 14 lives lost.

Recent heat waves have also had significant impacts on public health, agriculture, and infrastructure in Oman. For instance, a prolonged heat wave in 2020 caused record-high temperatures, resulting in increased heat-related illnesses, reduced agricultural yields, and infrastructure disruptions such as power outages due to high demand for air conditioning. The elderly and those with pre-existing medical conditions were particularly affected, and date palm yields, a crucial export for the country, significantly declined due to high temperatures.

In light of accelerating global warming and intensifying extreme weather events, Oman urgently needs to enhance the capacity and sustainability of its early warning center. This enhancement is crucial to address the impacts of heatwaves, droughts, dust storms, and tropical cyclones on urban areas, infrastructure, agriculture, water availability, energy demand, and overall sustainable development.

1.2. Consequences of Inaction

Failing to invest in and enhance early warning systems will have severe and escalating consequences for Oman:

- **Increased Economic Losses**: Without improved early warning systems, Oman will continue to suffer from the devastating impacts of cyclones, floods, and heatwaves. The absence of timely warnings and preparedness measures could lead to continued economic losses, estimated at billions of dollars. The estimated $7.30 billion USD in damages from past cyclones is likely to rise significantly with future events.
- **Infrastructure Damage**: Lack of advanced warning systems means infrastructure will remain vulnerable to extreme weather events. Roads, bridges, buildings, and other critical infrastructure will incur higher repair and maintenance costs due to frequent damage.
- **Agricultural Decline**: Inadequate early warnings for heatwaves and droughts will further reduce agricultural yields, threatening food security and the livelihoods of farmers. This decline will also impact Oman's export economy, particularly for crops like date palms.
- **Public Health Risks**: The absence of effective early warning systems for heatwaves will increase heat-related illnesses and fatalities, particularly among vulnerable populations such as the elderly and those with pre-existing health conditions.
- **Water Scarcity**: Droughts and inefficient water management will exacerbate water scarcity issues, affecting both agricultural and urban water needs. This will lead to higher costs for water procurement and management.
- **Energy Grid Strain**: Extreme temperatures without early warnings will cause unanticipated spikes in energy demand, straining the energy grid and leading to more frequent and prolonged power outages.
- **Overall Economic Instability**: The cumulative impact of these factors will result in higher healthcare costs, reduced productivity, and overall economic instability, hindering Oman's development goals. Additionally, this instability can deter private sector investment and negatively impact sustainable development efforts, as businesses may perceive a higher risk in operating within an environment prone to unmitigated climate hazards.
- **Failure to Meet Climate Commitments**: Inaction will impede Oman's ability to achieve its pledged carbon reduction targets of 21% by 2030 and carbon neutrality by 2050. This failure not only undermines national climate goals but also reduces Oman's credibility and standing in the international community, potentially affecting future funding and support for climate initiatives.

1.3. 2040 Outlook: The Financial and Economic Impact of Failing to Enhance Oman's Multi-Hazard Early Warning System

To develop a quantitative assumption for the consequences of inaction up to 2040 specifically related to not enhancing the Multi-Hazard Early Warning Center, a structured methodology was employed. This approach involved extrapolating from historical data, estimating potential future impacts based on climate projections, and accounting for the expected increase in the frequency and intensity of extreme weather events. This methodology ensures a robust estimate of the financial and socio-economic risks Oman could face if no action is taken to enhance its early warning systems and climate resilience.

- **Increased Economic Losses:** An analysis of past economic losses from major cyclones and heatwaves between 2002 and 2021, totaling $7.30 billion USD, serves as the baseline. With a conservative 20% increase in the frequency and severity of extreme weather events assumed for the future, economic losses are projected to rise to $8.76 billion USD. Adjustments for inflation and compounding effects further increase this figure to $13.14 billion USD by 2040.
- **Infrastructure Damage:** Historical data shows that infrastructure repair and maintenance costs following major events have averaged $500 million USD per event. With an expected increase in the number and severity of

events, future infrastructure damage is estimated to reach $9 billion USD by 2040, adjusted for inflation and frequency.

- **Agricultural Decline:** Past heatwaves and droughts have reduced date palm yields by approximately 10%. Future projections anticipate a 15% reduction in yields due to more frequent and severe heatwaves, leading to cumulative agricultural losses of $540 million USD over the next 18 years.
- **Public Health Risks:** Increased heat-related mortality rates, particularly among vulnerable populations, are expected to raise healthcare costs by 30%. This is projected to result in cumulative public health costs of $1.17 billion USD by 2040.
- **Water Scarcity:** A projected 20% increase in drought frequency is expected to exacerbate water scarcity issues, leading to higher water procurement and management costs. This is estimated to result in an additional $360 million USD in costs by 2040.
- **Energy Grid Strain:** Energy demand spikes during extreme heat events are anticipated to rise by 10%, potentially straining the energy grid. This could lead to an estimated $150 million USD in additional costs over the projection period.
- **Overall Economic Instability:** A 5% annual reduction in productivity across key sectors due to climate-related disruptions is projected, which could result in a significant cumulative GDP loss of $72 billion USD by 2040.
- **Failure to Meet Climate Commitments:** Inaction could lead to a failure in meeting climate commitments, resulting in potential losses of $500 million USD in international funding and economic opportunities by 2040.
- **Summary of Quantitative Assumptions:** The total quantified consequences of inaction by 2040 are estimated to be $96.86 billion USD (**Figure 59**). This figure encompasses projected economic losses, infrastructure damage, agricultural decline, public health costs, water scarcity, energy grid strain, overall economic instability, and the potential failure to meet climate commitments. These comprehensive estimates underscore the critical need for proactive measures to mitigate these risks by enhancing the Multi-Hazard Early Warning Center and improving Oman's climate resilience.

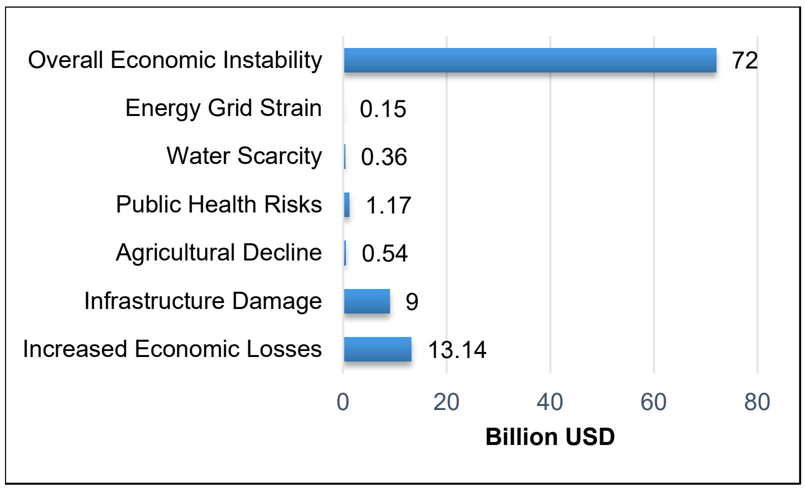


Figure 59: The Financial and Economic Impact of Failing to Enhance Oman's Multi-Hazard Early Warning System by 2040.

1.4. Alignment with Climate Goals and Targets

1.4.1. Strengthening Climate Preparedness: A Vital Step for Oman

As global warming accelerates and extreme weather events become more frequent, Oman urgently needs to enhance its early warning systems. The impacts of climate change pose significant threats to urban infrastructure, agriculture, water availability, energy demand, public health, and economic stability. Frequent flooding and dust storms damage roads, bridges, and buildings, leading to costly repairs and disruptions. Heatwaves and droughts reduce crop yields and increase water stress, threatening food security and farmers' livelihoods.

Droughts exacerbate water scarcity, affecting both agricultural and urban needs, making efficient water management and early warnings crucial for planning and conservation. Extreme temperatures cause spikes in energy demand, straining the energy grid and leading to power outages, while early warnings can help manage demand surges.

Heatwaves also increase heat-related illnesses, particularly among vulnerable populations, and early warnings allow for timely public health advisories. Additionally, extreme weather causes infrastructure damage, agricultural losses, and increased healthcare costs, impacting economic stability.

Enhanced early warning systems mitigate these effects, reducing financial burdens. Investing in advanced early warning systems saves lives, reduces economic losses, and enhances resilience. This aligns with global initiatives like the Sendai Framework, improving Oman's climate resilience and contributing to global efforts to combat climate change.

1.4.2. Need for Alignment with International Standards

Oman's early warning services must align with international standards and the Multi-Hazard Early Warning Systems Checklist established at the UNESCO, WMO, UNISDR Outcome of the first Multi-Hazard Early Warning Conference held from 22 to 23 May 2017 in Cancún, Mexico. This alignment is crucial for ensuring the effectiveness and reliability of the warning systems. Adhering to these standards guarantees that Oman's systems are compatible with global best practices, which facilitates international cooperation and support. To achieve this, significant investments in advanced technologies are essential. This includes state-of-the-art monitoring systems capable of providing accurate and timely data, enhanced satellite imagery for comprehensive coverage, radar systems for precise weather tracking, and ground-based sensors for real-time data collection. Additionally, advanced computational models are necessary for accurate predictions, while AI-assisted analysis can enhance data processing and decision-making. A robust communication infrastructure is also vital to ensure that warnings are disseminated quickly and efficiently to all relevant stakeholders. These investments will help Oman build a resilient and responsive early warning system that meets international standards and protects its communities from various hazards.

Collaborating with international partners is crucial for knowledge exchange, technical support, and capacity building. These partnerships can include working with United Nations agencies like the WMO and the UNDRR, engaging in regional initiatives, and participating in global initiatives like the "Early Warnings for All" to benefit from global resources and expertise. The "Early Warnings for All" initiative provides a comprehensive framework for strengthening Oman's National Multi-Hazard Early Warning System by leveraging cutting-edge technology, training local personnel, raising public awareness, and developing robust preparedness plans. Aligning with international standards through these efforts will enhance Oman's ability to predict, monitor, and respond to climate-related hazards. This alignment ensures that the country is better equipped to protect its citizens, infrastructure, and economy from the adverse impacts of climate change, while also contributing to global resilience and disaster risk reduction efforts.

2-Business Model Canvas for NMHEWS in Oman

The National Multi-Hazard Early Warning System (NMHEWS) in Oman serves as a crucial component in the country's strategy to mitigate the impacts of extreme weather events and climate-related risks. With the increasing frequency and intensity of such events due to climate change, NMHEWS must maintain sustainability, resilience, and alignment with both its core mission and Oman's broader strategic objectives. To achieve this, a conceptual business model has been developed, visualized through a Business Model Canvas, which provides a structured approach to how NMHEWS can create, deliver, and capture value for the nation (**Figure 60**).

2.1. Key Partnerships

Key Partnerships form the backbone of NMHEWS, enabling the system to leverage external expertise, technology, and resources. These partnerships include:

- **Meteorological Institutions:** Collaborations with local and international meteorological agencies ensure access to the latest data, models, and forecasting techniques.

- **International Climate Agencies:** Connections with global climate organizations like the World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC) keep NMHEWS at the forefront of climate science and integrate global best practices into its operations.
- **Technology Providers:** Partnerships with technology firms supply NMHEWS with cutting-edge tools and platforms necessary for data collection, analysis, and communication.
- **Research Universities:** Academic collaborations foster research and development, enhancing the system's forecasting accuracy and expanding its capabilities.
- **Local Communities:** Engaging local communities ensures that the system is responsive to the needs of the population, helping to build trust and ensure compliance with early warnings.

These partnerships are essential for the continuous improvement and operational efficiency of NMHEWS.

2.2. Key Activities

The operational efficiency and effectiveness of NMHEWS rely on its Key Activities, which include:

- **Real-Time Climate Data Collection:** A comprehensive network of sensors, Doppler radars, satellites, and automated weather stations collects real-time data on weather patterns, sea levels, and atmospheric conditions. These tools provide accurate and timely information critical for monitoring and predicting extreme weather events.
- **Data Analysis and Weather Forecasting:** Advanced algorithms and artificial intelligence analyze the collected data, generate weather forecasts, and predict the likelihood and impact of extreme weather events.
- **Risk Analysis and Cartography:** Detailed risk assessments for various climate hazards, such as flooding, droughts, storm surges, and coastal inundation, are conducted. Sophisticated cartographic tools produce high-resolution maps identifying vulnerable areas, aiding stakeholders in understanding potential risks and preparing accordingly.
- **Climate Modeling and Downscaling:** Climate models are developed and downscaled to fine resolutions, enabling localized climate projections. These models are essential for understanding long-term climate change impacts at a regional level, providing valuable information for infrastructure planning, resource management, and policy development.
- **Issuance of Timely Warnings:** Based on the analysis, risk assessments, and climate models, NMHEWS issues warnings to the public and relevant authorities. These warnings are tailored to different regions and sectors, ensuring they are actionable and effective.
- **Public Awareness Campaigns:** Regular campaigns educate the public about the system, its operation, and how individuals and businesses can prepare for and respond to warnings.
- **International Collaboration and Innovation:** Participation in global climate forums and research initiatives enhances methodologies and adopts new technologies that improve forecasting, risk analysis, climate modeling, and warning capabilities.

These activities are crucial for NMHEWS to fulfill its mission of protecting lives and property.

2.3. Key Resources

The success of NMHEWS depends on a robust set of Key Resources, which include:

- **State-of-the-Art Meteorological Equipment:** Doppler radars, satellite receivers, automated weather stations, and other technologies are essential for accurate data collection.
- **Skilled Personnel:** NMHEWS employs meteorologists, data scientists, IT specialists, and experts in Numerical Weather Prediction (NWP) models. These professionals are critical for interpreting data, conducting risk analysis, creating detailed cartographic maps, performing climate modeling and downscaling, and ensuring the timely dissemination of warnings.
- **High-Performance Computer (HPC) Clusters for Numerical Weather Prediction (NWP):** HPC clusters are crucial for running complex Numerical Weather Prediction models, enabling the processing of vast amounts of data and the generation of accurate weather forecasts and climate simulations.

- **Sophisticated Data Centers:** These centers house the infrastructure needed to process and store vast amounts of climate data securely and efficiently.
- **Robust Communication Channels:** Platforms for broadcasting warnings (e.g., mobile apps, SMS alerts, TV, radio) ensure the right message reaches the right audience at the right time.
- **Centralized Command and Control Center:** This facility coordinates all activities related to early warning, from data analysis to the issuance of alerts, ensuring a unified and coordinated response.

These resources ensure that NMHEWS operates at peak efficiency and remains reliable during critical times.

2.4. Value Proposition

NMHEWS's Value Proposition centers on its ability to provide:

- **Timely and Accurate Early Warnings:** Delivering early warnings that allow individuals, businesses, and government agencies to take preemptive actions, thereby reducing the potential damage and loss of life caused by natural disasters.
- **Public Safety and Risk Mitigation:** Alerting the public and relevant authorities to impending threats plays a vital role in safeguarding lives, properties, and livelihoods, particularly in vulnerable sectors such as agriculture, fisheries, and tourism.
- **Informed Decision-Making:** Supporting various sectors in making informed decisions through data-driven insights that guide infrastructure development, urban planning, and resource management.
- **Comprehensive Risk Analysis, Mapping, and Climate Modeling:** The detailed cartographic outputs, risk assessments, and localized climate models provided offer stakeholders a clear understanding of potential hazards, enabling them to prepare and respond more effectively to both immediate and long-term climate risks.

This value proposition underscores NMHEWS's role as a critical national asset in Oman's climate resilience strategy.

2.5. Customer Relationships

Establishing and maintaining strong Customer Relationships is vital for NMHEWS, achieved through:

- **Continuous Public Engagement:** Regular updates, press releases, and community meetings build trust and ensure that the population understands the importance of early warnings.
- **Private Sector Engagement:** NMHEWS works closely with businesses in sectors such as agriculture, construction, energy, and tourism to provide tailored climate information and risk assessments. This collaboration helps companies integrate climate resilience into their operations and strategic planning.
- **Awareness and Training Programs:** These programs educate both the public and specific sectors on how to respond to warnings and how to integrate risk reduction practices into their daily lives and operations.
- **Feedback Mechanisms:** Active feedback from users helps refine services and ensures that the system remains responsive to the needs of the public, private sector, and other stakeholders.

Prioritizing these relationships ensures that NMHEWS remains a trusted and reliable source of information.

2.6. Channels

NMHEWS uses a diverse array of Channels to disseminate warnings and forecasts, ensuring that information reaches all segments of the population:

- **Television and Radio Broadcasts:** Traditional media channels effectively reach a broad audience, including those without access to digital platforms.
- **Mobile Apps and SMS Alerts:** These channels provide real-time alerts directly to individuals, enabling immediate action.
- **Social Media Platforms:** NMHEWS leverages social media to reach younger demographics and ensure warnings are widely shared and disseminated.
- **Collaborations with Telecommunication Providers:** Partnering with telecom companies extends reach to remote and underserved areas, ensuring that no one is left uninformed.

These channels are crucial for ensuring that NMHEWS's messages are delivered quickly and effectively to all stakeholders.

2.7. Customer Segments

NMHEWS serves a diverse range of Customer Segments, each with unique needs and requirements:

- **General Public:** The primary audience for NMHEWS warnings, ensuring that individuals and families can protect themselves and their property.
- **Government Agencies:** These entities rely on NMHEWS data to coordinate emergency response efforts and make informed decisions about resource allocation and infrastructure development.
- **Businesses:** Sectors such as agriculture, fisheries, construction, energy, and tourism depend on accurate climate forecasts and risk assessments to manage risks and optimize operations.
- **International Organizations:** NMHEWS provides data and expertise to global entities working on climate resilience and disaster risk reduction.

Addressing the needs of these varied customer segments ensures broad utility and relevance.

2.8. Cost Structure

The Cost Structure of NMHEWS reflects the significant investments required to maintain its high level of service:

- **Equipment Procurement and Maintenance:** Regular updates and maintenance of meteorological equipment ensure accuracy and reliability.
- **Personnel Training and Salaries:** Continuous training and competitive compensation retain skilled professionals who can manage and operate the system.
- **Research and Development:** Ongoing R&D improves forecasting models, adopts new technologies, and stays ahead of emerging climate risks.
- **Public Engagement Campaigns:** These campaigns raise awareness and ensure that the public understands and trusts the system.

These costs are justified by the critical role NMHEWS plays in national safety and resilience.

2.9. Revenue Streams

To ensure financial sustainability, NMHEWS explores multiple Revenue Streams:

- **Government Funding:** As a national asset, NMHEWS receives significant funding from the government to support its operations and ensure its longevity.
- **Specialized Forecast Services:** Tailored forecasts and climate risk assessments are offered to specific sectors such as agriculture, fisheries, and construction, providing them with the data needed to optimize operations and reduce risks.

- **Climate Data Sales:** Researchers and private companies often require access to high-quality climate data, which NMHEWS provides for a fee.
- **Consultancy Services:** NMHEWS offers consultancy services to industries like construction and urban planning, helping them integrate climate resilience into their projects.
- **Partnerships and Sponsorships:** NMHEWS seeks partnerships and sponsorships from private sector companies, which can provide additional funding, technology, or other resources in exchange for brand visibility or other collaborative benefits.
- **Grants and Funds from International Organizations:** NMHEWS applies for grants and funding from international organizations focused on climate resilience, disaster risk reduction, and sustainable development. These funds support specific projects or initiatives within NMHEWS, enhancing its capabilities and outreach.

This diversified revenue model supports NMHEWS in maintaining and expanding its services, ensuring continued relevance and impact.

Figure 60: Business Model Canvas for NMHEWS in Oman.

3-Project Objective, Components and Theory of Change

The National Multi-Hazard Early Warning System (NMHEWS) in Oman is designed to strengthen climate resilience and enhance the country's capacity to manage climate risks. The primary objectives of the project are to improve the accuracy and timeliness of climate risk information, enhance the technical and institutional capacity for early warning and response, and promote climate-resilient infrastructure investments. The project is structured into three main components, each comprising specific activities aimed at achieving defined outputs and outcomes.

Component 1: Climate Information Services Delivery

- **Outcome 1**: Climate data and information collection processes are strengthened, enabling better decision-making.
    - **Output 1.1**: Policy and legislative frameworks for climate information services strengthened.
        - Activity 1.1.1: Establishing and operationalizing a National Framework for Climate Services (NFCS).
        - Activity 1.1.2: Establishing and operationalizing a National Disaster Risk Management Framework aligned with the Sendai Framework.
        - Activity 1.1.3: Building capacity for legislative and policy support for climate information services.
    - **Output 1.2**: Capacity of the NMHS enhanced through training and equipment upgrades.
        - Activity 1.2.1: Conducting capacity building for NMHS human resources.
        - Activity 1.2.2: Modernizing and maintaining weather monitoring equipment.
        - Activity 1.2.3: Strengthening software infrastructure and data management.
        - Activity 1.2.4: Conducting international collaboration and partnerships with organizations such as UNOCHA, WFP, IFRC, and ITU.
    - **Output 1.3**: Capacity of National Center for Emergency Management / Civil Defence and Ambulance Authority to support disaster risk management strengthened.
        - Activity 1.3.1: Conducting capacity building for National Center for Emergency Management / Civil Defence and Ambulance Authority, including risk modeling, risk transfer, and contingency planning.
        - Activity 1.3.2: Improving coordination between NMHS and National Center for Emergency Management / Civil Defence and Ambulance Authority, and private stakeholders through MOUs.
    - **Output 1.4**: Developing a business delivery model and financial strategy for sustainable climate services.
        - Activity 1.4.1: Advocate for increased budget allocation at the national level for NMHS and National Disaster Management Authorities (DMA).
        - Activity 1.4.2: Explore public-private partnerships or additional resources, such as specific digital forecasting modules.
        - Activity 1.4.3: Create incentives for private companies to invest in climate services, including attractive taxation and tax exemptions.

Component 2: Impact-Based MHEWS and Early Action

- **Outcome 2**: Communities' resilience to natural hazards is enhanced through increased awareness, timely and accurate warnings, and strengthened emergency preparedness and response capabilities.
    - **Output 2.1**: Improved disaster risk knowledge.
        - Activity 2.1.1: Conducting comprehensive multi-hazard and vulnerability assessments.
        - Activity 2.1.2: Developing dynamic multi-hazard maps.
        - Activity 2.1.3: Developing a consolidated risk and hazard database for early warning systems.
        - Activity 2.1.4: Engaging communities in local risk assessments.
    - **Output 2.2**: Strengthened detection, monitoring, analysis, and forecasting capabilities.
        - Activity 2.2.1: Installation and maintenance of automated warning monitoring systems and enhanced monitoring networks.
        - Activity 2.2.2: Implementing advanced data analysis, forecasting, and predictive tools.
        - Activity 2.2.3: Conducting regular system testing and capacity building.
        - Activity 2.2.4: Establishing institutional mechanisms and fostering partnerships between hydromet and national institutions.
    - **Output 2.3**: Improved and diversified systems for disseminating and communicating warnings for broader coverage and reach.
        - Activity 2.3.1: Developing and implementing multi-channel early warning communication and dissemination strategies.
        - Activity 2.3.2: Building community-based warning networks and conducting public awareness campaigns.
        - Activity 2.3.3: Establishing feedback and verification mechanisms.

        - Activity 2.3.4: Strengthening coordination with private sector telecommunication networks and media.
    - **Output 2.4**: Enhanced community and institutional readiness for effective disaster response.
        - Activity 2.4.1: Equipping National Center for Emergency Management / Civil Defence and Ambulance Authority with tools and equipment for disaster preparedness and response.
        - Activity 2.4.2: Developing community action plans and emergency protocols with regular reviews and updates.
        - Activity 2.4.3: Conducting regular community-based training and simulation exercises.
        - Activity 2.4.4: Establishing public awareness and education programs.
        - Activity 2.4.5: Conducting regular evaluation and lessons-learned exercises.

Component 3: Improving CIEWS for Investment and Financial Decisions

- **Outcome 3**: Adaptation actions are strengthened through increased integration of accurate climate information.
    - **Output 3.1**: Forecast-based actions established.
        - Activity 3.1.1: Developing forecast-based action protocols.
        - Activity 3.1.2: Setting up early warning triggers with measurable thresholds to trigger predefined early actions.
        - Activity 3.1.3: Training stakeholders, including relevant agencies, communities, and volunteers, on implementing forecast-based actions.
    - **Output 3.2**: Emergency funding mechanism created and operational.
        - Activity 3.2.1: Establishing the legal, institutional, and operational framework for the emergency fund.
        - Activity 3.2.2: Mobilizing and securing financial resources to operationalize and replenish the fund.

4-Theory of Change

4-1-Goals, outcomes, and impact

1-Goals, outcomes, and impact

The overarching goal of this project is to enhance Oman's resilience to climate-related challenges by building a comprehensive framework for climate risk management. Through strengthening climate information services, advancing impact-driven multi-hazard early warning systems, and facilitating strategic investments in climate-resilient infrastructure, the project aims to safeguard vulnerable communities, critical infrastructure, and economic assets. This integrated approach addresses systemic barriers, fostering evidence-based adaptation and preparedness.
If *Oman strengthens its climate information services, promotes early action through impact-based multi-hazard early warning systems, and integrates climate information into investment decisions for climate-resilient infrastructure,* ***then*** *communities in climate hazard and risk zones will become more resilient to climate change effects.* ***Because*** *the project systematically addresses key barriers to adaptation and preparedness, equipping communities and institutions with the information, infrastructure, and response capabilities needed to mitigate climate risks effectively.*

The project advances its goals through three interwoven components, each with targeted outcomes and outputs:

- The first component, Climate Information Services Delivery, focuses on strengthening climate data and information collection processes to improve decision-making (Outcome 1). This component enhances Oman's climate information framework by establishing a National Framework for Climate Services (NFCS) and aligning the National Disaster Risk Management Framework with global standards (Output 1.1). To support data accuracy and accessibility, it boosts the capacity of Oman's National Meteorological and Hydrological Service (NMHS) through training and equipment upgrades, in collaboration with global organizations such as UNOCHA, WFP, IFRC, and ITU (Output 1.2). Complementing these efforts, this component strengthens Oman's National Center for Emergency Management and the Civil Defence and Ambulance Authority with resources for risk modeling and coordination (Output 1.3). Additionally, output 1.4 promotes a sustainable business model and financial strategy for climate services by fostering public-private partnerships and offering incentives for private-sector engagement.

- The second component, Impact-Based Multi-Hazard Early Warning Systems and Early Action, focuses on enhancing community resilience to natural hazards by providing timely warnings and improved emergency preparedness (Outcome 2). Through Output 2.1, the project enhances disaster risk knowledge, equipping communities with actionable information about climate risks. Output 2.2 strengthens detection, monitoring, and forecasting capabilities within Oman's Early Warning Systems (EWS), ensuring timely responses to potential threats. Furthermore, output 2.3 deploys diversified systems for disseminating and communicating warnings, ensuring broader coverage and quick access for those at risk. By partnering with the Civil Defence and Ambulance Authority, National Center for Emergency Management, and IFRC, Output 2.4 builds community and institutional readiness for effective disaster response.
- The third component, Improving Climate Information and Early Warning Systems (CIEWS) for Investment and Financial Decisions, strengthens adaptation actions through the integration of climate information into planning and investment (Outcome 3). Output 3.1 establishes forecast-based actions, embedding climate resilience into urban planning and critical infrastructure strategies, particularly in high-risk coastal areas. Additionally, output 3.2 creates and operationalizes an emergency funding mechanism to support timely investments in climate adaptation, ensuring the resilience of infrastructure in vulnerable areas.

Upon successful implementation, the project will yield multiple benefits:

- Enhanced early warning systems will reach 5 million beneficiaries, with 40% female representation, promoting inclusive access to critical alerts.
- Strengthened capacity among government agencies will improve impact-based decision-making, supporting climate-resilient urban development.
- Institutional frameworks will adapt to align with resilience goals, creating an enabling environment for sustainable growth.
- Urban infrastructure planning will gain from accessible climate data, facilitating effective adaptation.
- Tangibly, Oman's physical assets will be better protected from climate impacts, and 4.5 million people will experience improved water security, underscoring the project's commitment to the health, safety, and resilience of Oman's population.

2-Barriers

In Oman, building a resilient climate adaptation framework faces multiple complex challenges. The primary barriers that this project will address are outlined below:

- **Barrier 1**: Policy and Legislative Gaps in Climate Information Integration.
- **Barrier 2**: Insufficient Budget and Resource Allocation.
- **Barrier 3**: Limited Private Sector Engagement in Climate Services.
- **Barrier 4**: Limited Access to Advanced Data Analysis and Forecasting Technology.
- **Barrier 5**: Insufficient Community Awareness and Engagement in Risk Assessment.
- **Barrier 6**: Inadequate Communication Infrastructure for Early Warning Dissemination.
- **Barrier 7**: Insufficient Financial Mechanisms for Sustainable Climate Action.
- **Barrier 8**: Gaps in Training and Capacity for Forecast-Based Action Protocols.
- **Barrier 9**: Challenges in Integrating Climate Information into Financial and Investment Decisions.

To address these core barriers, the project proposes a structured approach with interlinked activities and outputs, aligning with Oman's vision for a robust climate resilience framework.

For Barriers 1-3, the project emphasizes "Strengthening Climate Information Services" (Component 1) to integrate climate information into Oman's policy and legislative framework. Under Outcome 1, the project will enhance climate data processes for decision-making by establishing the National Framework for Climate Services (Activity 1.1.1), aligning Oman's frameworks with the Sendai Framework within the National Center for Emergency Management (Activity 1.1.2), and building capacity for legislative and policy support for climate information services (Activity 1.1.3), with the Directorate General of Meteorology as the primary beneficiary.

This effort will be supported by technical capacity upgrades at the National Meteorological and Hydrological Service (NMHS), including the procurement of modernized weather monitoring equipment (Activity 1.2.2), primarily a new Radar System for the Directorate General of Meteorology, which will be used and maintained for 15 years to enhance weather monitoring capabilities. Additionally, the project will invest in enhanced data analysis infrastructure (Activity 1.2.3), including:

- Geographic Information Systems (GIS) Platform for hazard mapping and real-time data analysis.
- High-Performance Workstations for climate modeling and large-scale data processing.
- Drone Technologies for hazard assessment, flood monitoring, and thermal imaging.
- AI Data Analysis Tools for predictive analytics and risk modeling.

To further enhance disaster risk management, Activity 1.3.2 will strengthen institutional coordination through Memorandums of Understanding (MoUs). The National Center for Emergency Management will enter into MoUs with the National Meteorological and Hydrological Service (NMHS) under the Ministry of Agriculture, Fisheries, and Water Resources, the Civil Defence and Ambulance Authority, and private stakeholders, including telecommunication providers, insurance companies, and infrastructure firms, to improve collaboration on early warning dissemination and risk reduction strategies.

The project will also encourage private sector engagement through an incentivized business model for climate services (Activity 1.4.3), ensuring sustainable funding and reduced reliance on public resources. The incentiveswill include taxation benefits, tax exemptions, subsidized access to climate data, preferential procurement for climate-resilient technologies, co-financing mechanisms, and regulatory incentives. The Environment Authority, in coordination with the Ministry of Finance, will oversee the implementation of these incentives, while GCF funds will not be used for direct financial incentives, focusing instead on policy-based mechanisms and public-private partnerships.

For Barriers 4-6, the focus is on "Promoting Impact-Based Multi-Hazard Early Warning Systems and Timely Responses" (Component 2) to enhance community resilience through accessible, accurate early warnings and strengthened emergency preparedness under Outcome 2. The project will increase community awareness and engagement by conducting public education campaigns about local climate risks (Activity 2.3.2) and establishing community-level risk assessment programs (Activity 2.1.4).
Simultaneously, the project will improve institutional capacity for early warning dissemination (Activity 2.2.4), with activities focused on developing multi-channel communication systems (Activity 2.3.1) to reach even remote populations. Furthermore, the project will build preparedness and response capacity through coordinated efforts from Oman's National Center for Emergency Management, Civil Defence and Ambulance Authority, and IFRC (Activity 2.4.3). This includes regular simulations, joint training sessions, and establishing rapid response teams (Activity 2.4.3).

For Barriers 7-9, the project emphasizes "Improving Climate Information and Early Warning Systems (CIEWS) for Investment and Financial Decisions" (Component 3). This component ensures that Oman's infrastructure and investment decisions are climate-resilient, focusing on adaptation under Outcome 3. The project will enhance the integration of climate information into urban planning and infrastructure investments by mapping climate hazard zones (Activity 3.1.1) and establishing forecast-based action protocols (Activity 3.1.1) to guide climate-smart urban expansion.

Additionally, the project will create an emergency funding mechanism (Activity 3.2.1) to support critical investments in resilient infrastructure, including flood-prone zones, improved drainage systems, and renewable energy adoption in high-risk areas (Activity 3.2.1). These targeted investments will address climate risks in vulnerable regions, safeguarding Oman's economic stability and public safety.

3-Assumptions

This proposal is built upon several foundational assumptions, each pivotal for the project's long-term success:

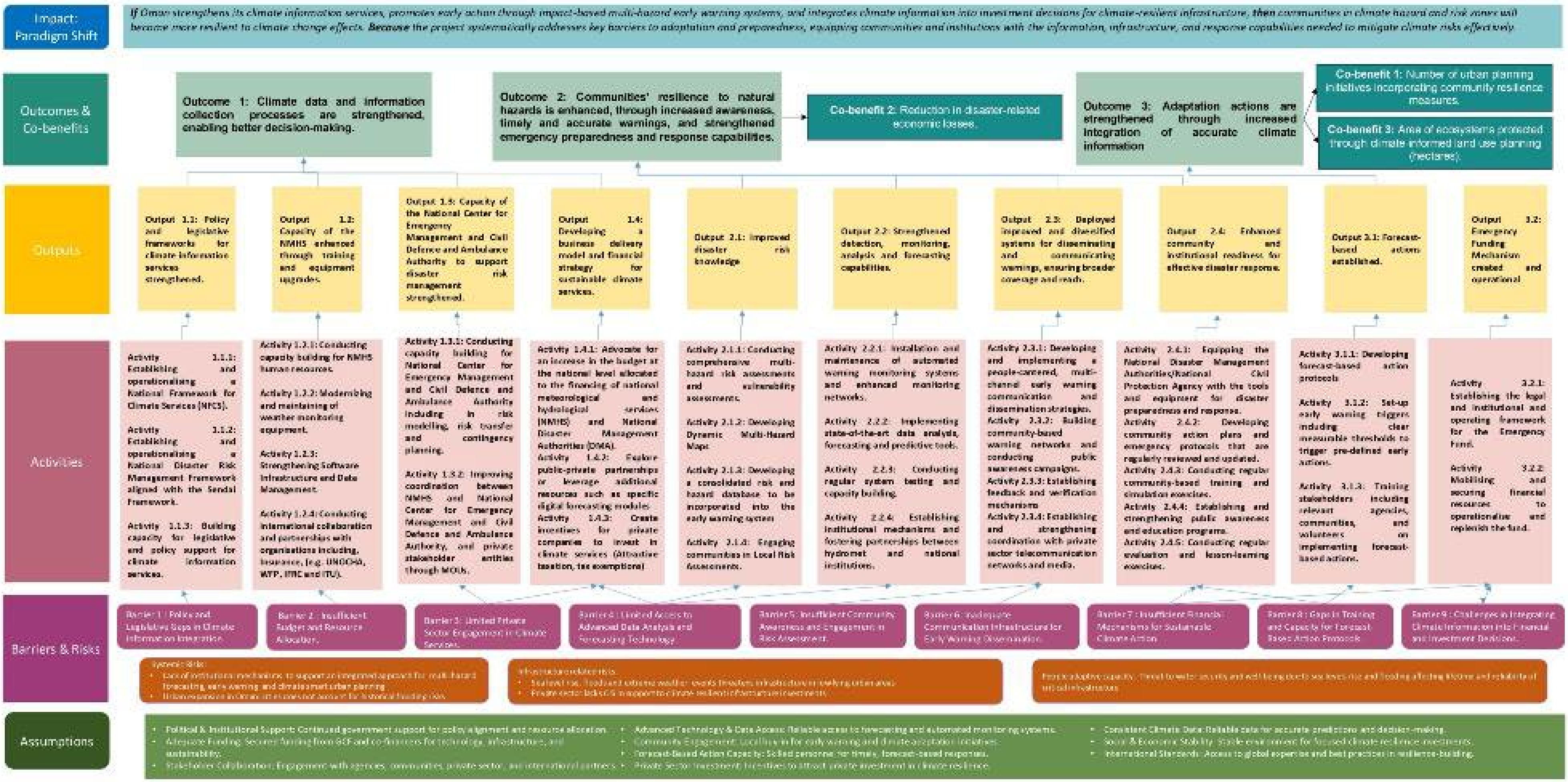
1. **Political and Institutional Support**: It is assumed that there will be continued support from the Omani government and relevant institutions, enabling policy alignment, resource allocation, and coordination among agencies involved in climate information services, early warning systems, and climate-resilient infrastructure.
2. **Adequate Funding Availability**: The project assumes that funding from the Green Climate Fund (GCF) and co-financing sources will be secured and sufficient to cover the necessary investments in technology, infrastructure, capacity-building, and program sustainability.
3. **Stakeholder Engagement and Collaboration**: Effective collaboration with key stakeholders, including national agencies, local communities, private sector actors, and international organizations, is assumed. This includes active involvement in consultations, knowledge sharing, and coordinated response efforts.

4. **Access to Advanced Technology and Data**: The proposal assumes that Oman will be able to procure and sustain advanced data analysis, forecasting technologies, and automated monitoring systems, which are essential for accurate climate predictions and proactive disaster management.
5. **Community Participation and Buy-In**: Successful implementation of early warning and climate adaptation strategies requires that local communities are willing to engage in awareness activities, adopt risk assessment protocols, and participate in preparedness initiatives.
6. **Capacity for Forecast-Based Action**: The proposal assumes that relevant institutions and personnel will gain and maintain the technical skills required to effectively use forecast data and respond with timely, forecast-based actions, facilitated by ongoing training and capacity-building programs.
7. **Private Sector Engagement**: It is assumed that incentives provided within the project will attract the private sector to invest in climate services and resilient infrastructure, fostering innovation and expanding resources available for climate adaptation efforts.
8. **Consistency of Climate Data**: Reliable and consistent climate data is essential for the success of the project's early warning systems. It is assumed that data integrity will be maintained throughout the project's duration, allowing for accurate predictions and informed decision-making.
9. **Social and Economic Stability**: The project assumes a stable socio-economic environment in Oman, allowing communities, institutions, and the private sector to focus on and invest in long-term climate resilience efforts without major disruptions.
10. **International Standards and Best Practices**: The project assumes access to international expertise and best practices in climate adaptation, early warning systems, and resilience-building, supported by partnerships with organizations like UNOCHA, IFRC, and WFP.

These assumptions provide a critical foundation for the project, as they underpin the activities and outputs essential for building a climate-resilient Oman.

The diagram below (**Figure 61**) illustrates the theory of change for this project. It showcases how the anticipated outputs of the project will address existing challenges to enhance the National Multi-Hazard Early Warning System in the Sultanate of Oman. This progress, in turn, is expected to drive the project towards achieving its intended outcomes and overarching objectives. Alongside this, the ToC diagram highlights the assumptions underpinning the project and the potential risks involved. Subsequent sections provide a more detailed breakdown of the project's activities.

Figure 61 : Theory of change diagram



5-Logframe and Indicators

5.1. Assessment of Paradigm Shift Potential for Oman's Multi-Hazard Early Warning System Enhancement

Table 10 provides a comprehensive assessment of the paradigm shift potential of the project focused on enhancing Oman's Multi-Hazard Early Warning System. The assessment is conducted across three key dimensions: scale, replicability, and sustainability. For each dimension, the table outlines the current state (baseline), assigns a rating, describes the potential target scenario, and details how the project will contribute to achieving that shift. The evaluation aims to illustrate how the project will catalyze a significant transformation in climate resilience in Oman by 2040, ensuring that climate information services (CIS) and early warning systems (EWS) are effectively scaled, replicated, and sustained to address the increasing climate risks facing the country.:

- **Scale:** Oman's current EWS and CIS have limited coverage, with low integration in urban planning (rated "Low"). The project targets significant expansion in these systems, aiming to enhance their reach and impact across more regions and sectors, thereby improving climate resilience.
- **Replicability:** Existing climate resilience efforts are fragmented and not widely replicated (rated "Low"). The project will establish a framework to facilitate replication, including private sector incentives and knowledge-sharing initiatives, ensuring that successful strategies can be applied in other regions and contexts.
- **Sustainability:** Current initiatives in Oman face sustainability challenges due to funding and policy gaps (rated "Low"). The project aims to address these issues by improving infrastructure, securing government support, and increasing private sector involvement, ensuring long-term sustainability of climate resilience efforts.

This assessment, together with the detailed breakdown in Table 9, underscores the project's potential to drive a paradigm shift in Oman's approach to managing and mitigating climate risks by 2040.

Table 10: Assessment of Paradigm Shift Potential for Oman's Multi-Hazard Early Warning System Enhancement.

Assessment Dimension	Current State (Baseline)	Rating	Potential Target Scenario	How the Project/Programme Will Contribute
Scale	Oman faces significant climate risks, including cyclones, floods, and heatwaves. The existing infrastructure for climate information services (CIS) and early warning systems (EWS) has moderate coverage and utilization in urban planning and infrastructure development. The current EWS has a medium capacity to provide accurate and timely climate risk information.	Low	The project aims to significantly expand the reach and effectiveness of CIS and EWS in Oman. Improvements will include mapping flood-prone areas, integrating CIS into urban planning, and mobilizing investments in critical coastal and flood-prone infrastructure. Enhanced capacity will allow scaling up climate resilience efforts across more regions and sectors in Oman.	The project will promote sustainable growth by integrating climate considerations into urban planning and infrastructure development. Key outputs include upgraded infrastructure for multi-hazard weather prediction, enhanced technical capacity of the Early Warning Centre, and support for private sector adoption of climate-resilient practices. Outcomes will include improved accuracy and timeliness of climate risk information, climate-smart urban expansion, and increased resilience of coastal and flood-prone infrastructure.
Replicability	Current efforts to implement climate resilience measures in Oman are fragmented and not widely replicated across different sectors or regions. A lack of a robust framework and insufficient knowledge sharing hinders replication.	Low	The project will establish a robust framework for climate resilience that can be replicated across sectors, markets, and regions. Key improvements will include tailored climate risk information for businesses, incentives for private sector investments in climate-resilient infrastructure, and	The project will enhance replication through key outputs such as support for private sector investments in climate-resilient infrastructure and a knowledge management strategy. Regional workshops, training sessions, and a knowledge-sharing platform will support replication in other countries, maximizing the project's impact.

			comprehensive training and workshops for stakeholders.	
Sustainability	Current climate resilience initiatives in Oman have limited long-term sustainability due to a lack of continuous funding and integration into national policies. Private sector involvement in climate resilience is minimal, limiting overall impact and sustainability.	Low	The project will enhance predictive capabilities, community preparedness, risk management, urban planning, and private sector engagement. Government support and economic benefits will ensure the sustainability of the project's outcomes.	The project will promote sustainability through upgraded infrastructure, enhanced technical capacity, and integration of CIS into urban planning. Outcomes include reduced losses of lives and infrastructure, improved operational capacity, and enhanced climate-resilient urban planning. Embedding climate resilience into national policies, securing continuous funding, and engaging the private sector will ensure long-term sustainability.

5.2. The Integrated Results Management Framework (IRMF) Core Indicators

The Integrated Results Management Framework (IRMF) Core Indicators provide a structured approach to tracking and evaluating the progress of projects aimed at enhancing resilience. **Table 11**, below highlights the selected IRMF Core Indicators for this project, along with the means of verification, baseline figures, and target values. These indicators focus on key result areas including support for vulnerable communities, improvements in health and well-being, and the resilience of infrastructure and built environments. This framework ensures that the project's outcomes are systematically monitored and aligned with broader goals for climate adaptation and mitigation. The IRMF Core Indicators show that the project aims to significantly enhance resilience in Oman by expanding early warning system coverage from 500,000 to 2.5 million people, reducing annual fatalities from climate-related disasters from 100 to 10, and increasing the number of resilient buildings from 100,000 to 600,000. These ambitious targets highlight the project's focus on protecting vulnerable populations and strengthening infrastructure against climate hazards. The clear, measurable goals and robust verification methods ensure effective monitoring and progress towards increased climate resilience.

Table 11: Monitoring Progress Using IRMF Core Indicators

GCF Result Area	IRMF Core Indicators (1-4)	Means of Verification (MoV)	Baseline	Target	
ARA1 Most vulnerable people and communities	**Supplementary 2.4:** Beneficiaries (female/male) covered by new or improved early warning systems	Survey reports, project monitoring data, and government records on early warning system coverage	500,000	Mid-term: 1,500,000	Final: 2,500,000
ARA2 Health, well-being, food, and water security	**Supplementary 2.7:** Change in expected losses of lives due to the impact of extreme climate-related disasters in the geographic area of the GCF intervention	Health and disaster response records, surveys, and statistical analysis of mortality rates during climate-related disasters	100 lives lost annually	Mid-term: 50 lives lost annually	Final: 10 lives lost annually
ARA3 Infrastructure and built environment	**Supplementary 2.6:** Beneficiaries (female/male) living in buildings that have increased resilience against climate hazards	Building inspection reports, resilience certification records, and project monitoring data	100,000 buildings	Mid-term: 300,000 buildings	Final: 600,000 buildings

6-Implementation Timeline

The project timetable (**Table 12**), spanning from 2026 to 2030, is structured into distinct components, each containing specific outputs and activities. The timetable's organization into quarterly milestones indicates a well-thought-out approach to achieving the project's objectives within a clearly defined timeframe.

Table 12: Project Timeline

COMPONENTS/ OUTPUTS	2026				2027				2028				2029				2030			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Component 1**																				
Ouput 1.1.																				
Activity 1.1.1:																				
Activity 1.1.2:																				
Activity 1.1.3:																				
Ouput 1.2																				
Activity 1.2.1:																				
Activity 1.2.2:																				
Activity 1.2.3:																				
Activity 1.2.4:																				
Output 1.3																				
Activity 1.3.1:																				
Activity 1.3.2:																				
Output 1.4.																				
Activity 1.4.1:																				
Activity 1.4.2:																				
Activity 1.4.3:																				
Component 2																				
Output 2.1.																				
Activity 2.1.1:																				
Activity 2.1.2:																				
Activity 2.1.3:																				
Activity 2.1.4:																				
Output 2.2																				
Activity 2.2.1:																				
Activity 2.2.2:																				

Activity 2.2.3:																				
Activity 2.2.4:																				
Ouput 2.3																				
Activity 2.3.1:																				
Activity 2.3.2:																				
Activity 2.3.3:																				
Activity 2.3.4:																				
Output 2.4																				
Activity 2.4.1:																				
Activity 2.4.2:																				
Activity 2.4.3:																				
Activity 2.4.4:																				
Activity 2.4.5:																				
Component 3																				
Output 3.1																				
Activity 3.1.1:																				
Activity 3.1.2:																				
Activity 3.1.3:																				
Output 3.2																				
Activity 3.2.1:																				
Activity 3.2.2:																				
Project Monitoring*		IR			APR				APR		IE		APR				CR			FE
Financial Reporting					AFS				AFS				AFS				AFS			AFS

IR=Inception Report

IE-Interim Evaluation

EC= Completion Report

FE= Final Evaluation

APR = Annual Performance Report

AFS=Audited Financial Statements

Chapter 4: Implementation Arrangements

1. Implementation Arrangements and Governance

1.1. Project Implementation Structure

1.1.1. Accredited Entity: UNIDO

The implementation of the project in Oman will be led by UNIDO as the Accredited Entity (AE) and the Environment Authority as an Executing Entity (**Figure 62**). UNIDO specializes in catalyzing technological solutions designed specifically to enhance industrial and infrastructure resilience. Its robust technological expertise and innovation-driven mandate uniquely position it to modernize Climate Information and Early Warning Systems through advanced digital technologies, predictive analytics, automated monitoring systems, and impact-based forecasting. Unlike conventional approaches that rely on existing infrastructure and methodologies, UNIDO facilitates next-generation technologies, supporting their development, transfer, and integration into real-time, cost-effective, and scalable climate resilience solutions. UNIDO brings the following distinctive strengths to this project:

- **Technological Expertise and Innovation Drive:** UNIDO has championed the Global Alliance on AI for Industry and Manufacturing, successfully catalyzing international partnerships across governments, industries, private sectors, academia, and civil society. This initiative promotes responsible and effective deployment of AI and frontier technologies, delivering multiple successful projects that demonstrate how advanced technology can drive sustainable development outcomes. UNIDO also enables the adoption of unmanned aerial vehicles (UAVs) for climate risk knowledge, risk assessment, preparedness, and relief efforts. By fostering partnerships and supporting innovation, UNIDO enables the integration of UAV technology to enhance climate hazard monitoring, damage assessment, and disaster response. Moreover, UNIDO enables the development and application of automated sensor networks, remote sensing technologies, and predictive modeling, ensuring that climate risk assessments and early warning forecasts are data-driven, real-time, and actionable through knowledge-sharing and capacity-building efforts. Additionally, UNIDO integrates feasibility analysis and investment risk assessment tools, including the COMFAR (4th Generation) software, a globally recognized tool for financial feasibility analysis and sustainable investment planning. The application of COMFAR strengthens the ability of industrial investors and policymakers to evaluate climate risks, cost-effectiveness, and economic resilience strategies within early warning system applications. The enhancement of the early warning System in Oman will not only enhances disaster preparedness but also supports risk-informed decision-making in industrial investment planning, infrastructure development, and economic resilience. UNIDO also actively contributes to shaping international policy through targeted global publications and forums, aligning global practices toward responsible innovation and technology utilization.
- **Global Cleantech Innovation Leadership:** Through its prominent Global Cleantech Innovation Programme, UNIDO has demonstrated significant expertise in nurturing and accelerating innovative, climate-resilient technologies from the conceptual stage to market deployment. This initiative equips UNIDO with the unique experience required to deploy networks of sensors and innovative monitoring technologies beyond traditional hydrometeorological infrastructure, substantially improving monitoring and forecasting capabilities for diverse climate-related hazards.
- Additionally, UNIDO supports startup-driven innovation by fostering partnerships between emerging technology firms and global research institutions. Through the Global Cleantech Innovation Programme, UNIDO accelerates the deployment of climate-smart solutions, ensuring that startups contribute to early warning system advancements. This includes AI-powered analytics, real-time environmental monitoring, satellite-based forecasting, and next-generation risk assessment tools, reinforcing Oman's ability to implement scalable, cost-effective disaster resilience technologies.
- **International Technology Transfer Capabilities:** Leveraging its extensive international network, UNIDO facilitates the transfer of cutting-edge technologies from global leaders in climate disaster forecasting, mitigation, and adaptation. For instance, Japan, internationally recognized for its advanced climate risk monitoring, disaster preparedness, and early warning systems, is among several strategic partners expressing strong willingness to collaborate with UNIDO. This partnership provides an opportunity for Oman to benefit directly from Japan’s expertise, technology, and best practices, significantly strengthening national capacities for climate risk management and resilience.

As the Accredited Entity, UNIDO oversees the overall implementation of the project, ensuring alignment with GCF objectives. Key responsibilities include:

- **Project Oversight:** Monitoring progress and ensuring that the project remains on track to meet its objectives.
- **Resource Management:** Managing funds and resources provided by the GCF and the Government of Oman.
- **Stakeholder Coordination:** Liaising with the Environment Authority and other partners to ensure effective collaboration.
- **Monitoring and Evaluation:** Regularly assessing project performance and addressing any challenges or risks.
- **Reporting:** Preparing detailed progress reports for the GCF, the Government of Oman, and the Nationally Designated Authority (NDA).
- **Governance Framework Development:** Establishing clear roles, responsibilities, and mechanisms to guide implementation.

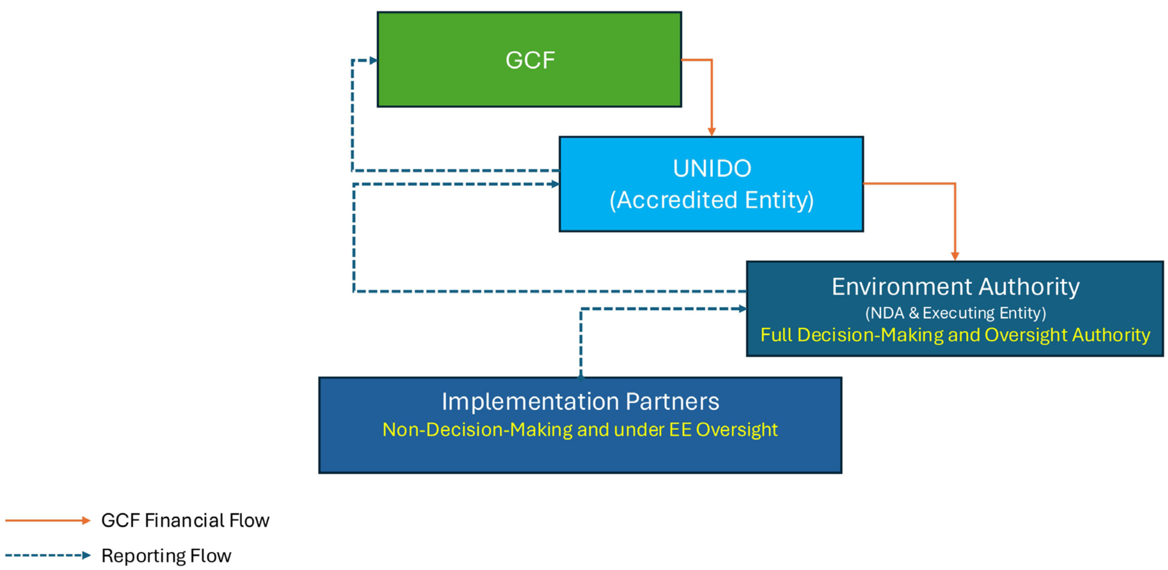


Figure 62: Project Implementation structure

1.1.2. Primary Executing Entity: Environment Authority

The Environment Authority will serve as the primary Executing Entity for the project. It will be responsible for leading on-the-ground implementation and ensuring the successful execution of all project components. Clear decision-making roles and processes will be established. Responsibilities will be outlined in a formal agreement with UNIDO, and all key decisions will be documented and effectively communicated to stakeholders to ensure transparency, accountability, and coordinated implementation. The implementation approach will be structured around well-defined roles, responsibilities, and institutional agreements, supported by a robust governance framework, as outlined below:

- **Agreement with UNIDO:** The Environment Authority will manage the procurement of goods and services required for project implementation, aligning with the Subsidiary Agreement established with UNIDO, which serves as the formal agreement under the Accredited Master Agreement (AMA) and Funded Activity Agreement (FAA). This grant agreement defines the roles, responsibilities, and obligations of both parties, including fund transfer protocols, governance and reporting standards, and compliance requirements, ensuring accountability and transparency in project execution.

- **Implementation Structure:** To execute specific project components, the Environment Authority will collaborate with designated entities for implementation:
  - **Component 1:** Climate Information Services Delivery, implemented with the Directorate General of Meteorology.
  - **Component 2:** Impact-Based Multi-Hazard Early Warning Systems and Early Action, executed through the National Center for Emergency Management and the Civil Defence and Ambulance Authority.
  - **Component 3:** Improving Climate Information and Early Warning Systems for Investment Decisions, facilitated by the Ministry of Finance.

  These Implementation Partners are not Executing Entities under the Accredited Master Agreement (AMA) or Funded Activity Agreement (FAA) but serve as service providers supporting project implementation within their respective mandates. Their engagement through MoUs ensures alignment with project objectives and compliance with GCF requirements. The Environment Authority enters into MoUs for the implementation of activities under different components; however, it retains full decision-making authority over the implementation of activities within those components. As the primary Executing Entity, the Environment Authority is responsible for overseeing collaboration, consolidating updates, and submitting comprehensive reports to UNIDO, ensuring effective coordination and accountability within the project framework.

1.1.3. Secondary Implementing Entities

The project will involve the following secondary implementing entities, formalized through Memorandums of Understanding (MoUs), each responsible for specific components under the leadership of the Environment Authority:

- Directorate General of Meteorology: Responsible for Component 1: Climate Information Services Delivery, as outlined in the MoU with the Environment Authority.
- National Center for Emergency Management and Civil Defence and Ambulance Authority: Jointly responsible for Component 2: Impact-Based Multi-Hazard Early Warning Systems and Early Action, under an MoU established with the Environment Authority.
- Ministry of Finance: Responsible for Component 3: Improving Climate Information and Early Warning Systems for Investment Decisions, as specified in the MoU with the Environment Authority.

These Implementation Partners are not Executing Entities under the Accredited Master Agreement (AMA) or Funded Activity Agreement (FAA) but serve as collaborating institutions supporting project implementation within their respective mandates. Their engagement through MoUs ensures alignment with project objectives and compliance with GCF requirements. The Environment Authority enters into MoUs for the implementation of activities under different components; however, it retains full decision-making authority over the implementation of activities within those components. As the primary Executing Entity, the Environment Authority is responsible for overseeing collaboration, consolidating updates, and submitting comprehensive reports to UNIDO, ensuring effective coordination and accountability within the project framework.

2-Project Activities Implementation and Responsibilities

The project activities will be implemented by UNIDO, the Environment Authority, and through joint collaboration between both entities to ensure the effective execution of project objectives. The division of responsibilities is outlined as follows:

- **UNIDO as the Sole Executing Entity:** UNIDO will be responsible for activities that focus on technical capacity building, policy framework development, training, technology transfer, and system enhancements. These activities contribute to strengthening climate information services, early warning systems, and financial resilience. UNIDO will act as the sole Executing Entity for the following activities:
  - Activity 1.1.1, Activity 1.1.2, Activity 1.2.1, Activity 1.2.4, Activity 1.3.1, Activity 2.1.1, Activity 2.1.4, Activity 2.3.1, Activity 2.3.3, Activity 2.3.4, Activity 2.4.2, Activity 2.4.3, Activity 3.1.1, Activity 3.1.2, and Activity 3.2.2.
- **Environment Authority as the Sole Executing Entity:** The Environment Authority will lead activities related to policy implementation, institutional capacity building, regulatory frameworks, infrastructure upgrades, and procurement of climate-related equipment (funded by GCF and co-financing sources). The Environment Authority will act as the sole Executing Entity for the following activities:
  - Activity 1.1.3, Activity 1.2.2, Activity 1.2.3, Activity 1.3.2, Activity 1.4.1, Activity 1.4.2, Activity 1.4.3, Activity 2.1.2, Activity 2.2.2, Activity 2.2.3, Activity 2.2.4, Activity 2.3.2, Activity 2.4.1, Activity 2.4.4, Activity 2.4.5, Activity 3.1.3, and Activity 3.2.1.

- **Joint Execution Responsibilities:** Two activities require a collaborative approach between UNIDO and the Environment Authority to ensure effective implementation. These activities focus on risk assessment, early warning system integration, and strengthening multi-hazard preparedness. The division of responsibilities is outlined below:
    - Activity 2.1.3 – Developing a Consolidated Risk and Hazard Database for Early Warning Systems:
        - UNIDO (Budget Note E3): Develops the risk and hazard database.
        - Environment Authority (Budget Note E4): Procures necessary equipment, including GIS platforms, high-performance workstations, drones (various types), AI data analysis tools, and modeling/simulation software.
    - Activity 2.2.1 – Installation and Maintenance of Automated Warning Monitoring Systems
        - Environment Authority (Budget Note F1): Procures non-contacting radar level gauges for enhanced monitoring networks.
        - UNIDO (Budget Note F2): Develops operational guidelines for data analysis and predictive modeling to improve risk assessment and decision-making.

3-Project Governance and Operational Structure

To facilitate effective coordination, decision-making, and accountability, the project is supported by a robust Governance and operational structure. This structure integrates strategic oversight, operational management, and technical execution, structured across three interconnected levels (**Figure 63**).

a) Project Steering Committee (PSC): The Environment Authority is responsible for establishing, hosting, and – in its NDA role – chairing the PSC, ensuring alignment with national policies and policy governance requirements. The PSC provides strategic direction, oversight, and decision-making for the project, including the Environmental and Social Action Plan (ESAP), Stakeholder Engagement Plan (SEP), and (Grievance Redress Mechanism (GRM). Its members include senior representatives from:

- UNIDO (Accredited Entity)
- The Environment Authority (Executing Entity)
- Key government ministries and national authorities

The PSC ensures high-level alignment with project objectives, resolves strategic challenges, and communicates milestones and outcomes to donors and stakeholders, ensuring compliance with GCF standards.

b) Project Implementation Unit (PIU): The Environment Authority is responsible for establishing and hosting the Project Implementation Unit (PIU) as part of its role as the Executing Entity. The PIU is responsible for day-to-day implementation, oversight and coordination of Technical Working Groups (TWGS), that provide technical expertise and recommendations for environmental, and social risk management. In line with the agreement with UNIDO, the Environment Authority will retain full decision-making authority over project activities under its responsibility. The PIU ensures that TWGs support the effective implementation of ESAP, SEP and GMR. To strengthen this role, the PIU will include dedicated staff responsible for the implementation, monitoring, and reporting of the ESAP, SEP, and GRM. This staff member will coordinate the integration of environmental and social safeguards across project activities and maintain regular communication with stakeholders, including the management of feedback and grievances. Furthermore, the PIU will ensure that minimal environmental and social risks, particularly those associated with the monitoring stations, are avoided, mitigated, and monitored effectively. The PIU will be composed of::

- UNIDO Project Manager
- NDA Representative
- Environment Authority Project Manager
- Senior Manager from implementation partners

The PIU ensures the smooth execution of activities by consolidating inputs from TWGs and facilitating coordination among stakeholders.

c) **Technical Working Groups (TWGs):** The Environment Authority, as the legal entity responsible for establishing and hosting the TWGs, ensures that their work aligns with national policies and project objectives. The TWGs are structured to support the day-to-day implementation of the project's three main components, as well as ESAP, SEP, and GRM, ensuring effective technical execution and coordination. The TWGs will be composed of six working groups, each dedicated to one of the three main project components and the implementation of ESAP, SEP, and GRM. Each TWGs includes:

- UNIDO international experts
- National experts from Implementation Partners

The TWGs provide technical outputs, address challenges, and report progress to the PIU. They support the implementation, monitoring, and reporting of ESAP, SEP, and GRM, ensuring integration of environmental and social safeguards, stakeholder engagement, and grievance redress into project activities

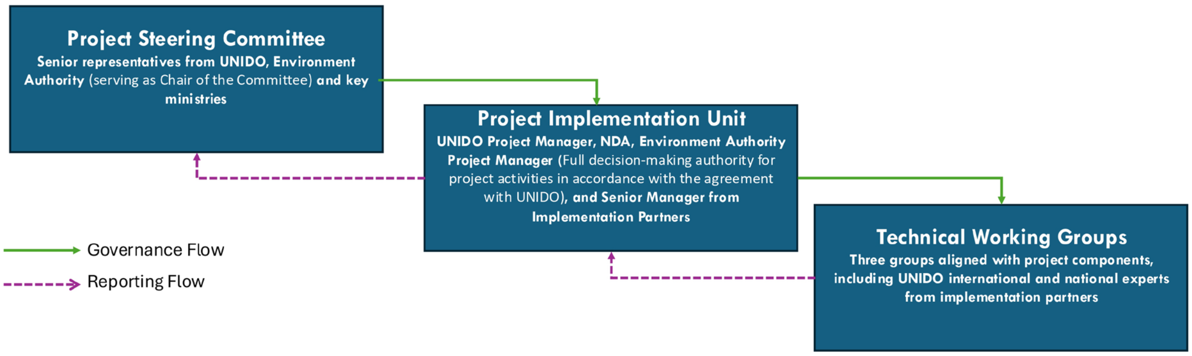


Figure 63: Project Governance and Operational Structure

2. Capacity Assessment and Due Diligence

2.1. Assessment of Executing Entities' Capacities

2.1.1. Accredited Entity (UNIDO)

UNIDO, the Accredited Entity for this project, brings over 20 years of experience in implementing the Montreal Protocol in Oman. UNIDO has a proven track record of managing complex, large-scale industrial projects with substantial funding, demonstrating its capability to oversee and execute activities effectively. Additionally, UNIDO has successfully implemented a GCF readiness project focused on low-carbon transportation development in Oman. Currently, UNIDO is implementing the National Adaptation Plan (NAP) and the First Biennial Transparency Report (BTR) of Oman under the UNFCCC. This extensive experience in environmental projects and climate-related initiatives ensures that UNIDO is well-equipped to manage the NMHEWS project, leveraging its expertise to ensure successful outcomes.

2.1.2. Primary Executing Entity (The Environment Authority)

The Environment Authority, acting as the Primary Executing Entity) through a formal agreement with UNIDO, has the institutional capacity, technical expertise, and governance structure to implement the project effectively. It has demonstrated success in managing environmental initiatives and possesses a deep understanding of Oman's climate challenges. While well-equipped, capacity-building in advanced technology and data analysis will ensure optimal performance.

2.1.3. Secondary Implementing Entities

The following government entities will implement specific components under Memorandums of Understanding (MoUs) with the Environment Authority:

- Directorate General of Meteorology:
  - Responsible for Component 1: Climate Information Services Delivery.
  - Capabilities: Strong expertise in climate data collection, forecasting, and alignment with national policies.
- National Center for Emergency Management and Civil Defence and Ambulance Authority:
  - Jointly responsible for Component 2: Impact-Based Multi-Hazard Early Warning Systems and Early Action.
  - Capabilities: Proven disaster management expertise but requires improvements in integrating climate information systems for enhanced early action.
- Ministry of Finance:
  - Responsible for Component 3: Improving Climate Information and Early Warning Systems for Investment Decisions.
  - Capabilities: Strong governance and financial expertise but needs capacity-building to integrate climate risk data into investment decisions.

2.2. Due Diligence Findings

2.2.1. UNIDO

- **Compliance with Legal and Regulatory Frameworks:** UNIDO operates in full compliance with international and national legal and regulatory standards, including those of the United Nations and the GCF. No significant legal risks were identified that could hinder the project's implementation.
- **Financial Stability and Accountability:** UNIDO has demonstrated robust financial management practices, as evidenced by its successful management of large-scale projects. The organization's financial systems ensure transparency, accountability, and compliance with GCF funding requirements.
- **Risk Management:** UNIDO has established comprehensive risk management frameworks, including systems for identifying, assessing, and mitigating potential risks associated with project implementation.
- **Previous Project Performance:** UNIDO's successful track record in Oman, particularly in projects related to climate resilience and low-carbon development, underlines its capability to manage and implement the NMHEWS project effectively.

2.2.2. The Environment Authority

- **Compliance with Legal and Regulatory Frameworks:** As a government entity, the Environment of Authority adheres to Oman's legal and regulatory requirements for climate change affairs, with no significant legal impediments to project execution.
- **Technical Expertise:** The Environment Authority has demonstrated a high level of technical expertise in climate affairs and early warning systems, crucial for the successful execution of the NMHEWS project.
- **Local Knowledge and Experience:** The Environment Authority's deep-rooted presence in Oman and extensive experience in managing climate-related challenges provide a strong foundation for implementing the NMHEWS.
- **Capacity for Project Execution:** The Environment Authority is well-equipped to manage the technical aspects of the project, although further capacity-building in specific areas of advanced technology and data analysis has been recommended to ensure optimal performance.

These assessments confirm that both UNIDO, as the Accredited Entity, and the Environment Authority, as the Executing Entity, have the necessary capacities, experience, and systems in place to successfully implement the NMHEWS project. The due diligence findings also indicate that while both entities are well-prepared, targeted capacity-building initiatives will further enhance their ability to manage and execute the project effectively.

2.2.3. Secondary Implementing Entities

The project will involve the following government entities as secondary implementing partners, formalized through Memorandums of Understanding (MoUs), with findings summarized based on their compliance, expertise, and capacity:

1. **Directorate General of Meteorology**
    - **Compliance with Legal and Regulatory Frameworks**: Fully aligned with national policies on meteorology and climate information services.
    - **Technical Expertise**: Possesses established capabilities in climate data collection, analysis, and forecasting.
    - **Local Knowledge and Experience**: Extensive experience in providing meteorological services tailored to Oman's needs.

- **Capacity for Project Execution**: Adequately equipped with infrastructure and skilled personnel to implement Component 1 with minimal additional support.

2. **National Center for Emergency Management and Civil Defence and Ambulance Authority**
    - **Compliance with Legal and Regulatory Frameworks**: Operate within the national framework for disaster management and emergency response.
    - **Technical Expertise**: Strong field expertise in emergency management and disaster risk reduction.
    - **Local Knowledge and Experience**: Proven track record in managing crises and collaborating with local communities.
    - **Capacity for Project Execution**: Requires enhancements in integrating climate information systems and early action protocols to maximize effectiveness for Component 2.
3. **Ministry of Finance**
    - **Compliance with Legal and Regulatory Frameworks**: Fully adheres to financial governance and public investment guidelines.
    - **Technical Expertise**: Demonstrates expertise in managing large-scale financial systems and investment portfolios.
    - **Local Knowledge and Experience**: Familiar with economic and financial conditions affecting investment decisions in Oman.
    - **Capacity for Project Execution**: Capacity-building efforts needed to incorporate climate risk information into investment decision-making for Component 3.

These entities will operate under the frameworks defined by their MoUs, ensuring alignment with the Environment Authority's oversight and compliance with Green Climate Fund requirements.

Annex 1

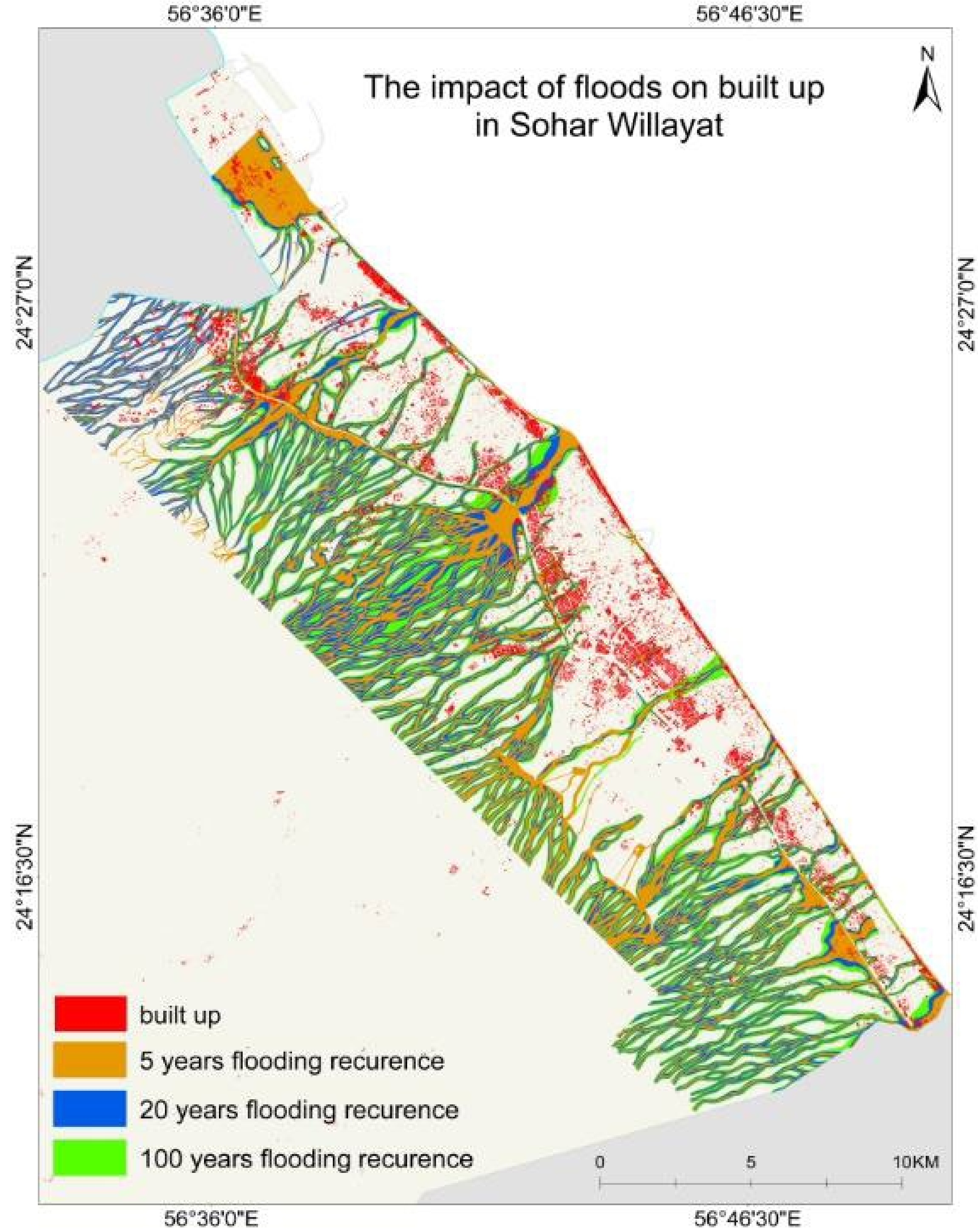


Figure 1: High (5years recurrence), Medium (20 years recurrence) and Low (100 years recurrence) flooding risk for Built-Up area in main cities in Oman.

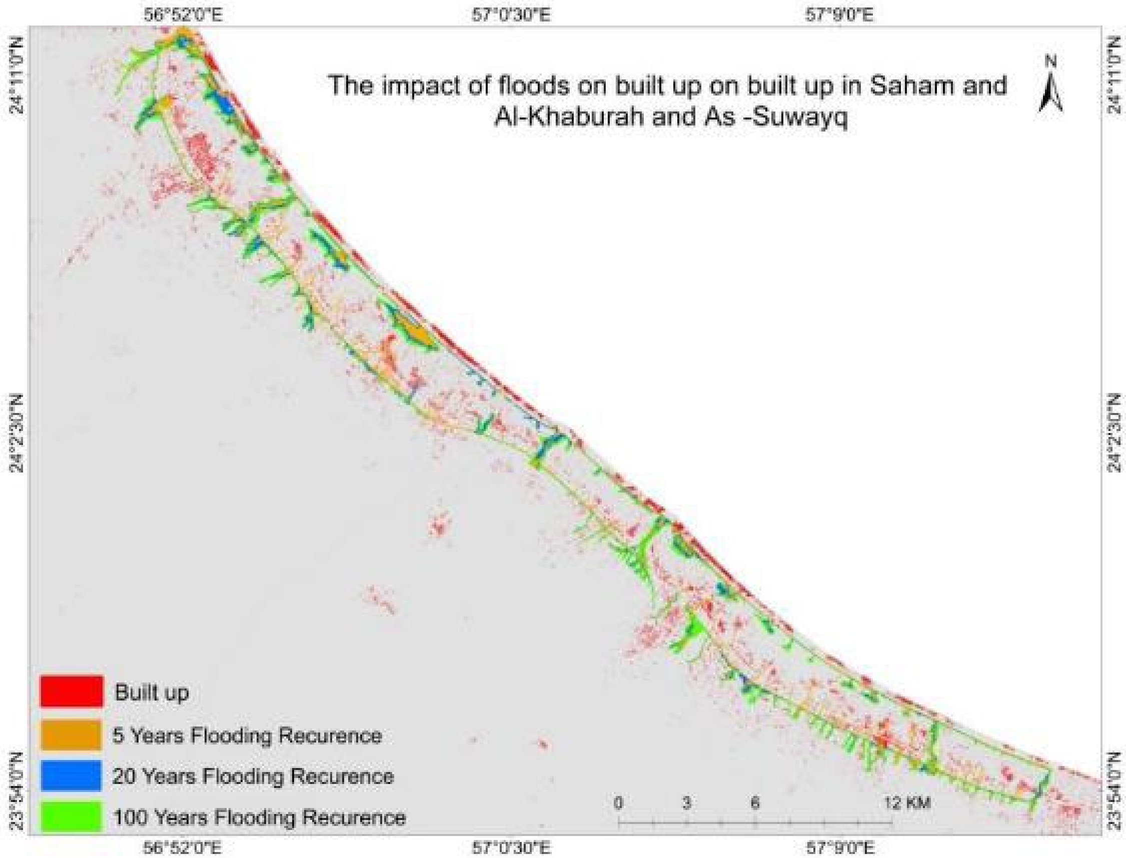


Figure 2: Delineations of High (5years recurrence), Medium (20 years recurrence) and Low (100 years recurrence) flooding risk zones in Saham, Al-Khaburah and As-Suwayq.

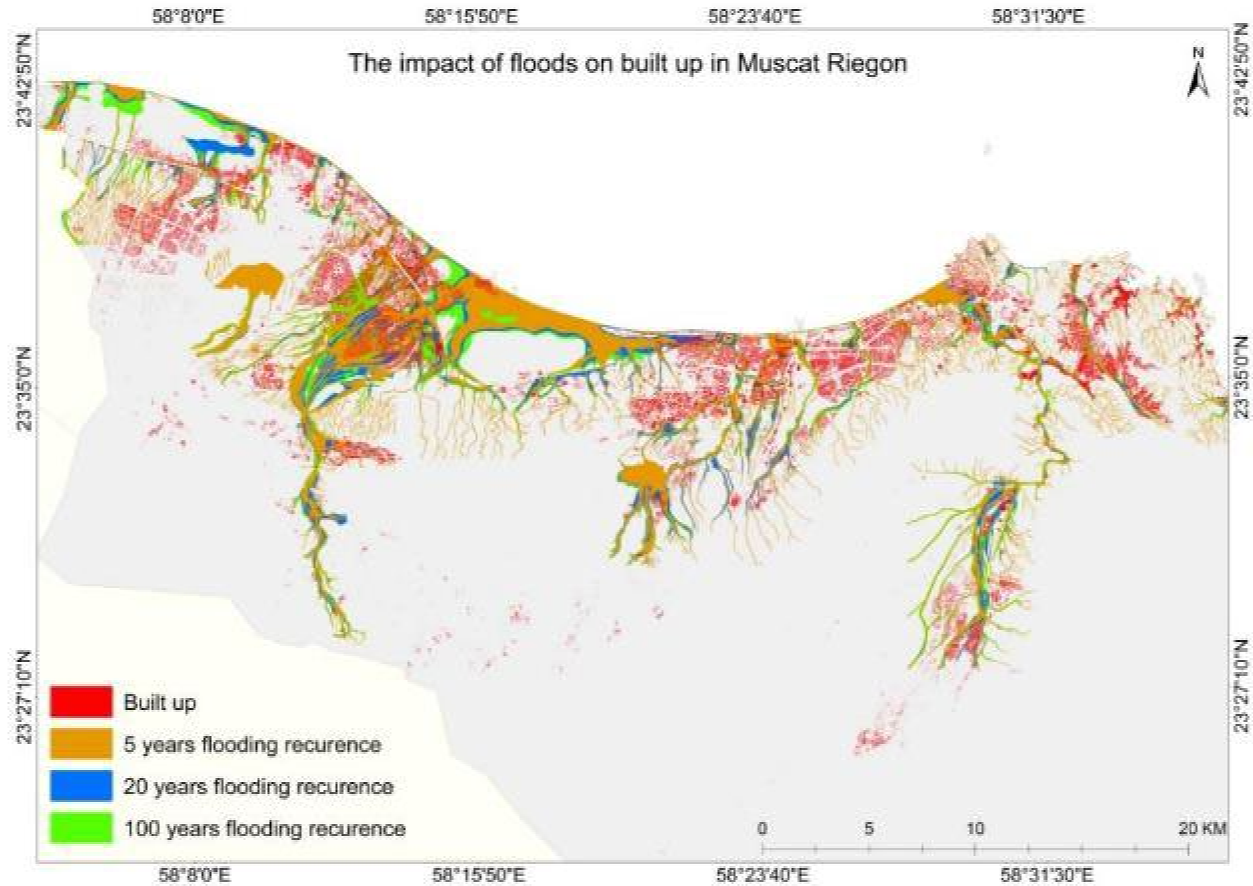


Figure 3: Delineations of High (5years recurrence), Medium (20 years recurrence) and Low (100 years recurrence) flooding risk for built-Up area in Muscat

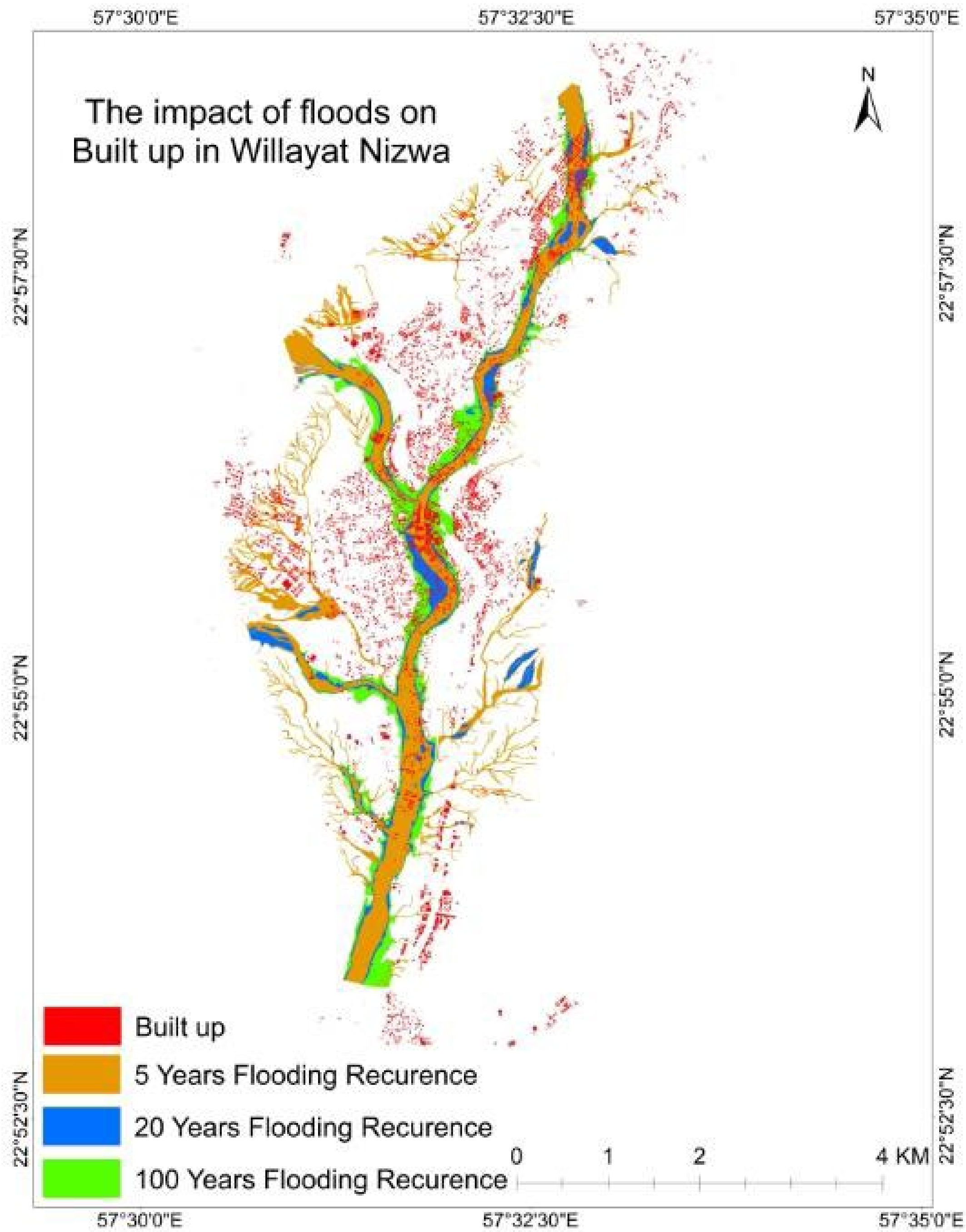


Figure 4 : Delineations of High (5years recurrence), Medium (20 years recurrence) and Low (100 years recurrence) flooding risk for built-up area in Nizwa.

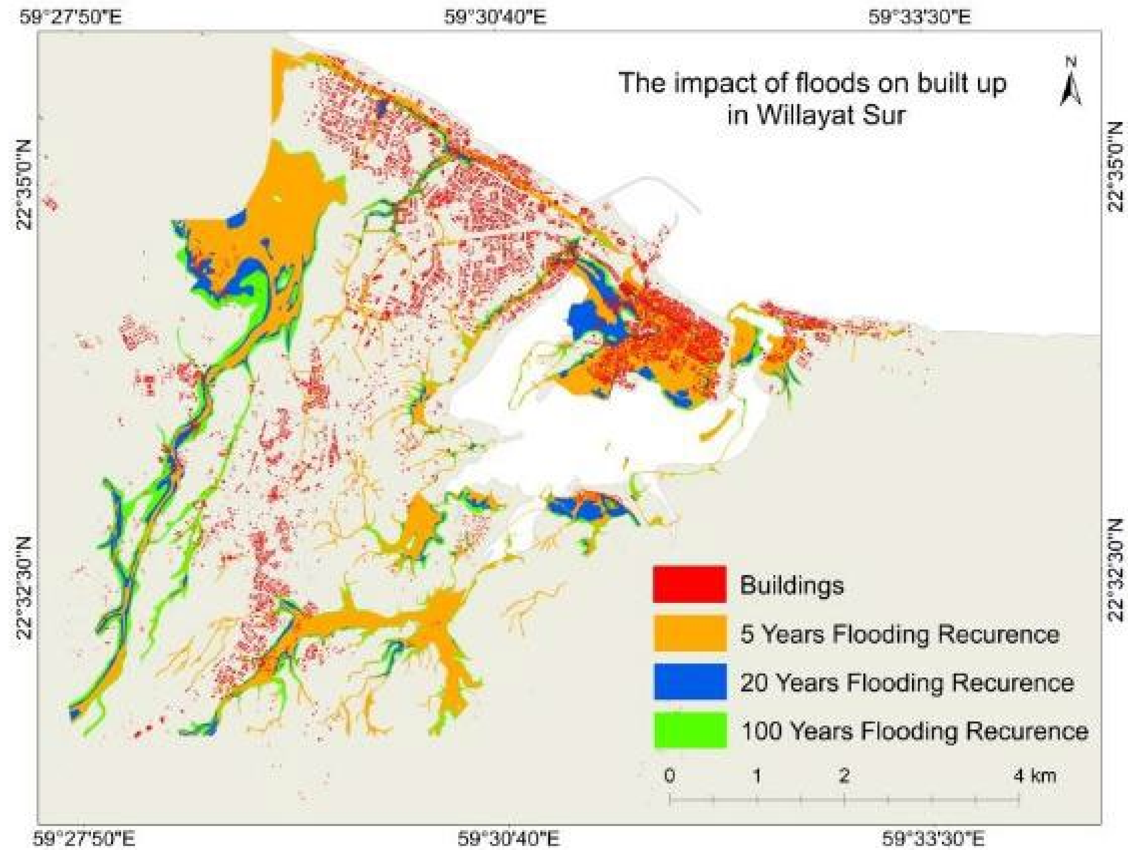


Figure 5 : Delineations of High (5years recurrence), Medium (20 years recurrence) and Low (100 years recurrence) flooding risk for built-up area in Sur.

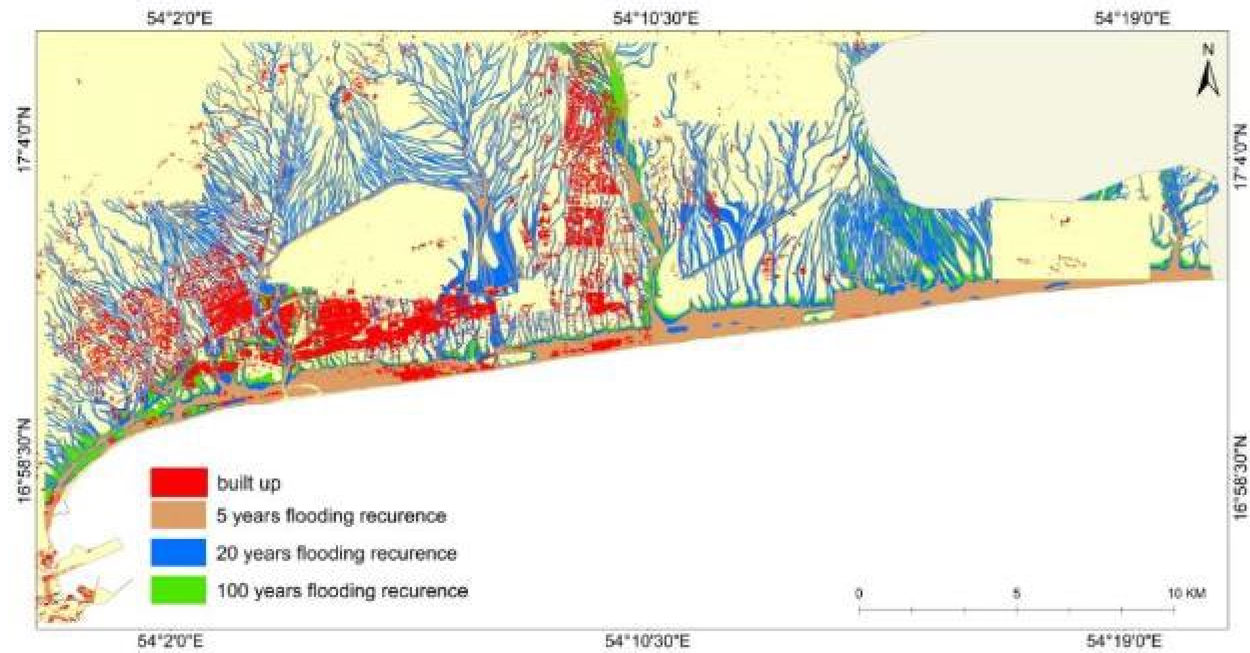


Figure 6 : Delineations of High (5years recurrence), Medium (20 years recurrence) and Low (100 years recurrence) flooding risk for built-up area in Salalah

Annex 2

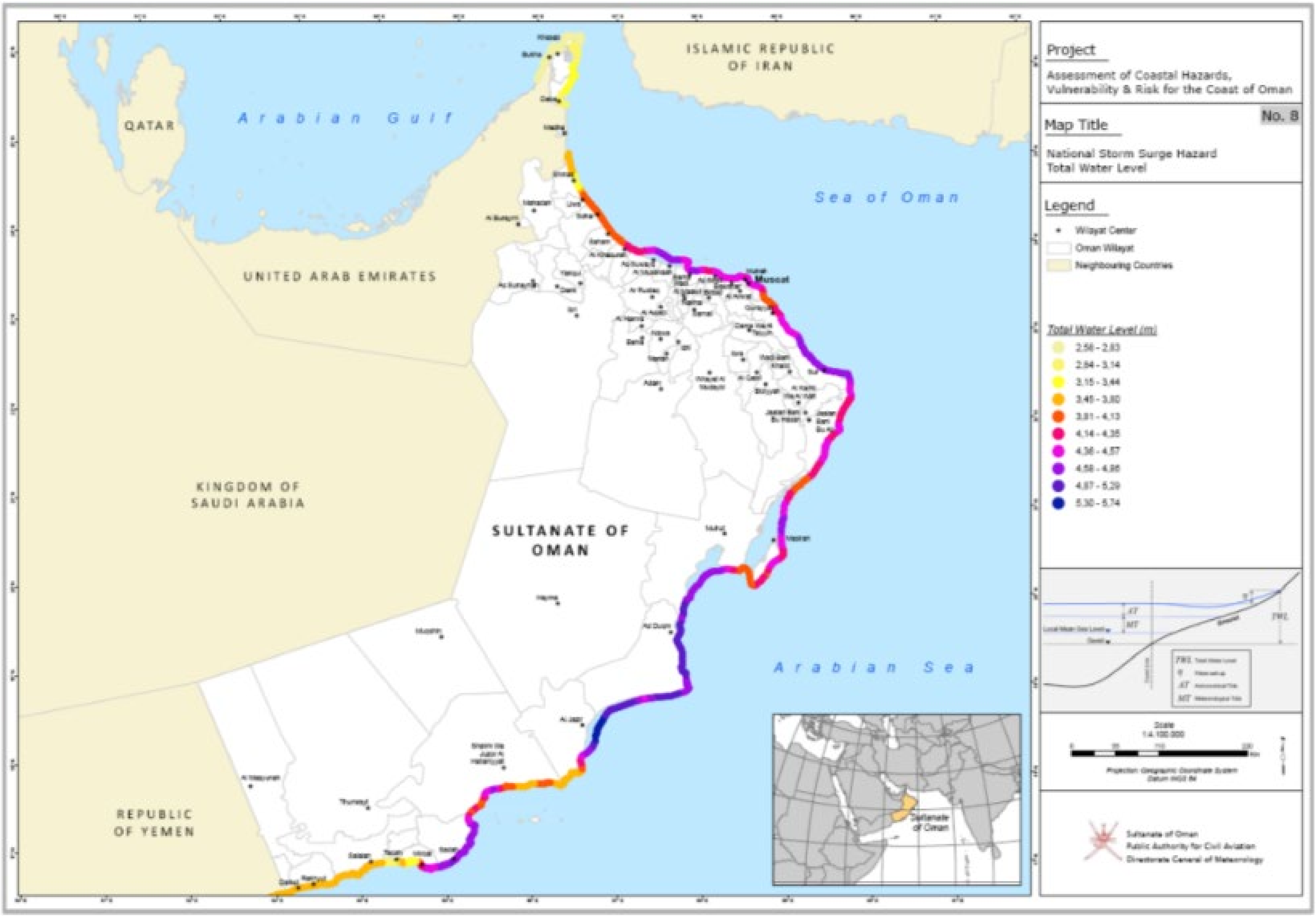


Figure 1. Map of the National Storm Surge Hazard (Total Water Level in Meters).

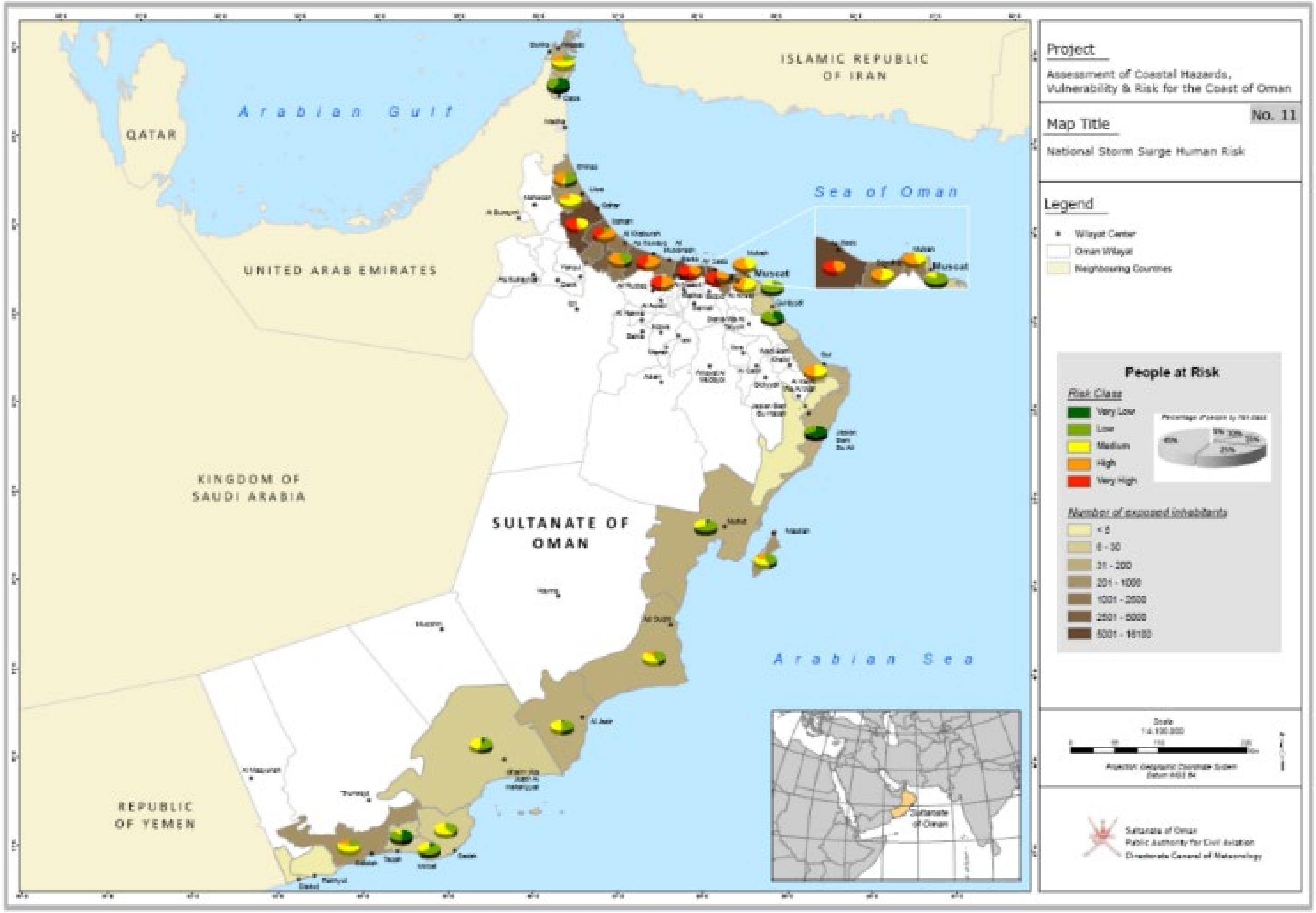


Figure 2. Map of the National Storm Surge Human Risk.

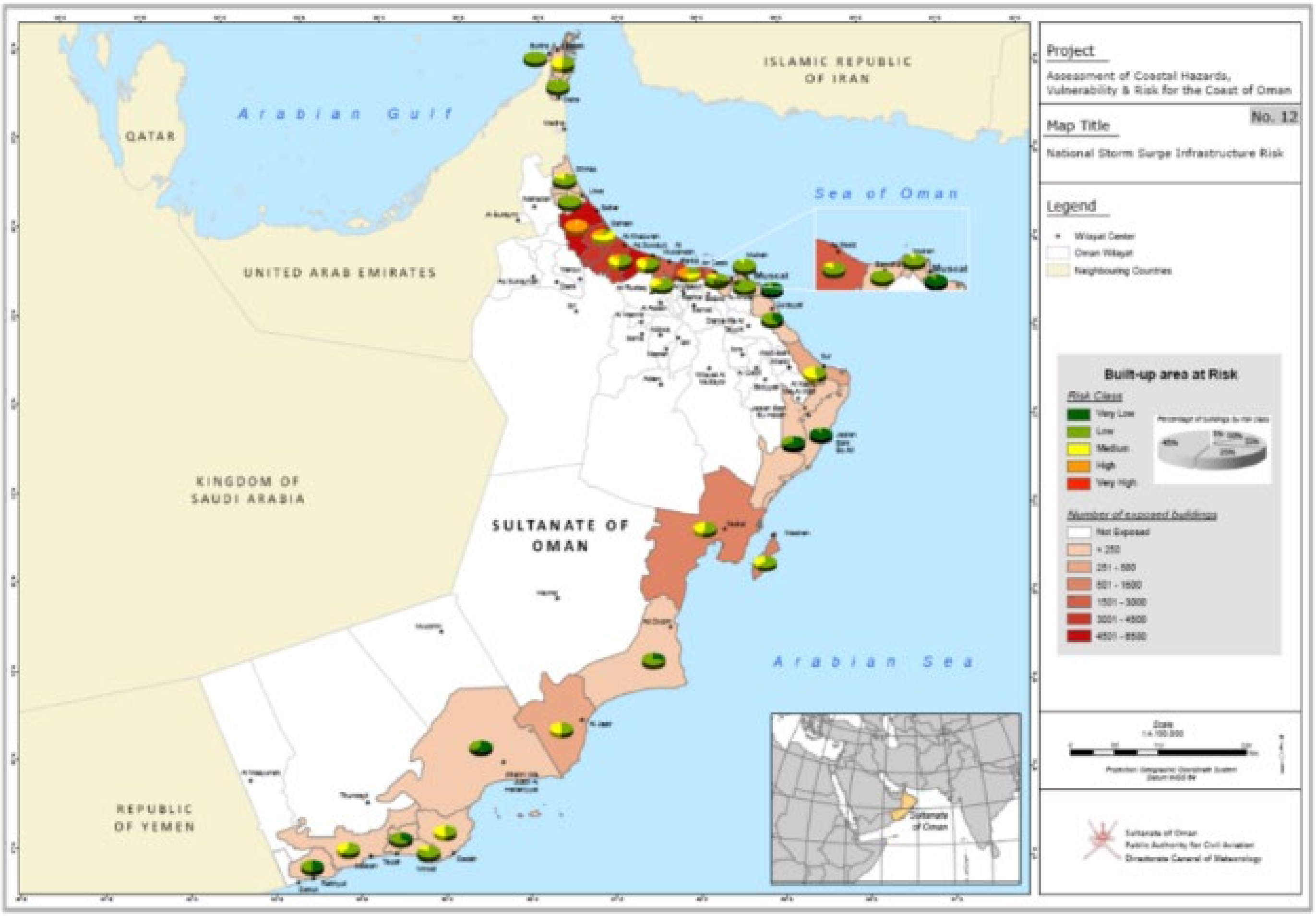


Figure 3. Assessment of Coastal Hazards, Vulnerability & risk for the coast of Oman.