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Proceedings of
TWAS-AREP Online Workshop

Climate Change

Lens on Priorities

Editor
Mohamed A. Abdrabo

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Foreword

Our world today is facing tangled developmental challenges; on top comes world climate changes, and many Arab countries are among the most affected countries by climate change negative impacts, thus many players in the Arab region are giving unprecedented attention to climate issues.

Since the Bibliotheca Alexandrina (BA) is a center of excellence in the production and dissemination of knowledge, the BA and TWAS Arab Regional Partner (TWAS-AREP), we find that our responsibility is to promote awareness on such pressing matter as climate change.

So under the framework of TWAS-AREP Young Scientists Training Program, we held an online workshop "Climate Change: Lens on Priorities". We chose the title "Lens on Priorities", as the workshop focused on climate change priority areas for the Arab region. It highlighted climate change related risks and concerns with particular focus on the Arab region, and it discussed the top research priorities that our young researchers should pay attention to.

We are delighted to publish selected outcome viewpoints and research efforts that were presented by our distinguished scholars and speakers during TWAS-AREP online workshop "Climate Change: Lens on Priorities".

Prof. Ahmed A. Zayed
Director
Bibliotheca Alexandrina
TWAS-AREP Coordinator

TWAS-AREP Regional Partner

The World Academy of Sciences for the advancement of science in developing countries (TWAS) is a global science academy based in Trieste, Italy, since 1983. It works to advance sciences and engineering for sustainable prosperity in developing countries.

TWAS has established five regional partners to help organize activities and disseminate information. The regional partner which is concerned with the Arab region is the TWAS Arab Regional Partner (TWAS-AREP) which is hosted by the Bibliotheca Alexandrina through the Center for Special Studies and Programs (CSSP) since 2005.

TWAS-AREP aims to promote scientific capacity and excellence in the region through annual activities for Arab scientists, especially young researchers, such as a Regional Prize and young affiliates program. This is in addition to organizing annual meetings for the Arab members, young scientist conferences, workshops, and public lectures for young scientists' capacity building and promoting public awareness of science.

TWAS and Italy

In the early 1980s, elite Italian scientists joined in the work of Pakistani Nobel Laureate Abdus Salam to establish TWAS. Soon, with the backing of top Italian lawmakers, Italy provided an early grant that allowed TWAS to build momentum. Since TWAS' inception, the Italian Government has provided core funding for the Academy's operations. The partnership with Italy is still central to the Academy's activity.

TWAS mission is to recognize, support, and promote excellence in scientific research in the developing countries; respond to the needs of young scientists in countries that are still developing in science and technology, promote South-South and South-North cooperation in science, technology, and innovation; and encourage scientific research and sharing of experiences in solving major challenges facing developing countries.

TWAS is a programme unit of the United Nations Educational, Scientific and Cultural Organization (UNESCO), which, under a 1991 agreement, assumed responsibility for administering TWAS funds and personnel. In 2004, the Italian Government adopted a law that ensured an annual financial contribution to the Academy's operation. Representatives of the Italian Government and UNESCO are members of the TWAS Steering Committee, which meets annually to discuss financial matters.

For additional information on TWAS and TWAS-AREP, please visit:
www.bibalex.org/TWAS-AREP/.
www.bibalex.org/cssp.

TWAS-AREP Online Workshop
Climate Change: Lens on Priorities

The World Academy of Sciences for the advancement of science in developing countries Arab Regional Partner (TWAS-AREP) organized an online workshop on Climate Change within the framework of the Young Scientists Training Program, 7–8 December 2021, within the framework of TWAS-AREP Young Scientists Training Program.

The workshop aimed at highlighting the climate change priority issues, research priorities, and climate change-related risks and concerns for developing countries with particular focus on the Arab region. Also, it presented practical experiences from different developing regions on tackling climate change and the role of research in these regards.

The workshop discussed the impact of climate change on public health and presented some case studies on how climate change relates to the spread of toxins, epidemics, and diseases. It also presented case studies and examples of how to prevent its negative effect on the different sectors (such as agriculture, environment, water, deserts, and forests).

The workshop tackled future challenges as well posed by climate change, and the effective use of available resources to overcome these challenges and adapt to climate change.

The workshop provided the opportunity for young researchers under the age of 40 years to network with experts and researchers from developing countries.

About TWAS-AREP Young Scientists Training Program (YSTP)

It is a training program designed for young scientists. It offers a wide range of topics of interest for researchers who undertake scientific research across the science and technology spectrum.

Workshop Agenda

Tuesday, 7 December 2021	
10:00–11:00 am	**Welcome Note** • **Marwa Elwakil**, Head, Academic Research Sector, Bibliotheca Alexandrina, Egypt • **Abdelnasser Tawfik**, Founder Director, Egyptian Center for Theoretical Physics (ECTP) and TWAS Council Member, Egypt **Opening Session** • **Abdelnasser Tawfik**, Founder Director, Egyptian Center for Theoretical Physics (ECTP) and TWAS Council Member, Egypt
11:00 am – 12:30 pm	**Session I: Climate Change in the Arab Region** *This session will discuss the climate change status in the Arab Region. It will discuss major challenges facing Arab countries. The session will present case studies and examples on how to prevent its negative effect on the different sectors (such as agriculture, environment, water, deserts, and forests). It will also discuss climate change adaptation.* • **Mohamed A. Abdrabo**, Professor, Environmental Economics; and Head, Alexandria Research Center for Adaptation to Climate Change, Alexandria University, Egypt • **Samira Omar Asem**, Principal Research Scientist and Former Director General, Kuwait Institute for Scientific Research (KISR), Kuwait • **Hani Sewilam**, Academic Director, Department of Engineering Hydrology; and Executive Director, UNESCO Chair in Hydrological Changes and Water Resources Management, RWTH Aachen University, Germany
12:30–1:00 pm	**Break**

1:00–2:00 pm	**Session II: Climate Change: Actions across the Regions** *This session will present the status of climate change across the regions, as well as the actions that were taken or should be taken to mitigate the climate change effect around the world, with the help of some case studies.* • **Adalberto Luis Val**, Senior Researcher with INPA National Institute for Research of the Amazon, Brazil • **Cheikh Faye**, Department of Geography, U.F.R. Sciences and Technologies, UASZ, Laboratoire de Géomatique et d'Environnement, Senegal
2:00–3:00 pm	**Session III: Climate Change and Sustainable Development** • **Max Paoli**, Program Coordinator, TWAS, Italy
Wednesday, 8 December 2021	
11:00 am – 12:30 pm	**Session IV: Climate Change: Future Challenges** *This session will reflect on future challenges presented by climate change, and the efficient use of available resources to overcome such challenges.* • **Mohamed Bayoumi**, Assistant Residential Representative, Environment and Climate Change Team Leader, United Nations Development Programme (UNDP), Egypt • **Jauad Elkharraz**, Executive Director, Regional Center for Renewable Energy and Energy Efficiency (RCREEE), Egypt • **Salah Arafa**, Professor, Department of Physics, The American University in Cairo, Egypt
12:30–1:00 pm	**Break**

1:00–2:00 pm	**Session V: The Impact of Climate Change on Public Health** *This session will discuss the impact of climate change on public health. It will present some case studies on how the climate change is associated with the spread of toxins, pandemics, and diseases.* • **Maha Ghanem**, Head, Department of Forensic Medicine and Clinical Toxicology, Faculty of Medicine, Alexandria University, Egypt • **Alya A. Arabi**, Associate Professor, Department of Biochemistry, College of Medicine and Health Sciences, United Arab Emirates
2:00–2:30 pm	**Break**
2:30–3:30 pm	**Session VI: What TYAN Can Provide for Young Scientists in Relation to Climate Change (Open Discussion)** *This session will tackle what TYAN can provide young scientists in relation to climate change. The session will be an open discussion to provide some ideas on how a multidisciplinary network of scientists can support young researchers with their research endeavors in areas related to climate change.* • **Roula Abdel-Massih**, Professor, Department of Biology, Faculty of Sciences, University of Balamand, Lebanon • **Murad Al Damen**, Professor, Inorganic Chemistry, Department of Chemistry, Faculty of Science, University of Jordan, Amman, Jordan • **Max Paoli**, Program Coordinator, TWAS, Italy
3:30–4:00 pm	**Closing Session**

Table of Contents

Chapter 1
Climate Change: An Introduction

Mohamed A. Abdrabo[(1)]
Alexandria Research Center for Adaptation to Climate Change (ARCA)
Alexandria University

1.1 Background

Some gases including carbon dioxide, methane, nitrous oxide, and ozone naturally present in the Earth's atmosphere play a role similar to the glass or plastic sheets in a greenhouse. That is allowing the sunrays that reach the earth to pass through but trap some of the thermal radiation returning from the surface of the earth into the atmosphere and not allowing it to escape into space. These gases are known as Greenhouse Gases (GHGs). The increase in the concentrations of these gases in the atmosphere, since the industrial revolution, has led to the acceleration of this mechanism and thus the retention of larger proportions of the thermal radiation returning from the surface of the earth, which leads to a gradual rise in the earth's temperature and the resulting change in the climate.

This introductory chapter intends to discuss the phenomenon of climate change and its causes, beginning with a brief review of the components of the Earth's climate system. This is followed by a definition of the phenomenon of climate change, greenhouse gases, and changes in their concentrations in the atmosphere, with a review of the contributions of countries and different economic sectors to these emissions. This is followed by a discussion of the relationship between greenhouse gas concentrations and climate change, and the debate surrounding the phenomenon of climate change, while the last part of this chapter deals with the reasons behind the occurrence of climate change from an economic perspective.

1.2 Components of Earth's Climate System

It is typically believed that the earth's climate system is the atmosphere. However, this system is much more complicated than that as it is the product of the interaction of five sub-systems: the atmosphere, the lithosphere, the hydrosphere, the biosphere,

(1) E-mail: mabdrabo@alexu.edu.eg.

and the cryosphere,[(2)] (Figure 1.1). This means that the prevailing climate pattern is determined depending on the mechanism by which these sub-systems interact with each other, and the Global Climate Models (GCM) rely on this mechanism to develop scenarios about climate change in the long term. Each of these sub-systems is briefly reviewed.

1.2.1 Atmosphere

The atmosphere forms a thin layer of gases surrounding planet Earth, starting from the surface of the earth or the sea, and the density of these gases gradually decreases with height, as there is no clear boundary for this layer separating it from outer space. The atmosphere consists of a mixture of several gases; The two main gases are oxygen and nitrogen which together make up about 99% of the total mass and volume of gases in the Earth's atmosphere. The atmosphere also includes other gases, but in small proportions, such as carbon dioxide, ozone, methane, and water vapor, which are also present in variable proportions. Despite the small percentages of water vapor, carbon dioxide, ozone, and methane, they play a very important role in atmospheric processes because of their radiative and thermodynamic properties,[(3)] meaning that these gases play a major role in the transfer of heat and water around the world.

1.2.2 Lithosphere

The lithosphere is the solid outer crust of planet Earth, the semi-solid earth beneath the crust, and the liquid mass near the center of the planet. Where these components are organized in the form of layers with varying physical and chemical properties. The outer layer of the lithosphere consists of loose soil rich in nutrients, oxygen, and silicon. The outer surface of the lithosphere is also irregular, with high mountain ranges, spacious plains, and deep valleys along the ocean floor and all other forms of Earth's surface. The lithosphere plays an important role in the climate system, through its land cover/land use as well as its radiative and thermodynamic properties.

1.2.3 Hydrosphere

The Earth's hydrosphere includes all forms of liquid water, whether on the Earth's surface or in its interior, with a mass of about 1.4 billion km^3, of which sea and ocean water (salty water) represents about 97.5% of the total of that water. While fresh water in lakes, rivers, and groundwater constitutes the remaining about 2.5%. The hydrosphere occupies the largest part of the Earth's surface, more than 75% of the total area of the planet. It is worth noting that the water bodies interact greatly

(2) G. Thomas Farmer, *Modern Climate Change Science: An Overview of Today's Climate Change Science,* SpringerBriefs in Environmental Science (New York, NY: Springer, 2015).

(3) Kshudiram Saha, *The Earth's Atmosphere: Its Physics and Dynamics* (Berlin: Springer, 2008).

with the atmosphere as it absorbs a large proportion of the energy present in the atmosphere, which influence marine systems and dynamics.

1.2.4 Biosphere

The biosphere includes all the living elements of various ecosystems on planet Earth, which include all plant and animal organisms, as well as the dead organic matter that they produce. The biosphere exchanges materials and energy with the water, atmosphere, and lithosphere, which helps activate the geochemical cycles of carbon, nitrogen, phosphorus, sulfur, and other elements on the globe. From an ecological point of view, the biosphere is the "global ecosystem", which includes the totality of biodiversity on Earth and performs all kinds of biological functions, including photosynthesis, respiration, decomposition, nitrogen fixation, and removal.

1.2.5 Cryosphere

The cryosphere includes all frozen areas of the Earth's hydrosphere, including glaciers, ice caps, icebergs, ice in lakes and rivers, permafrost, seasonal snow, and ice crystals in the atmosphere. Glaciers are very sensitive to changes in the global average temperature because temperatures fluctuate around the freezing point in most parts of Earth. Permanent ice caps cover about 10.8% of Earth's surface and most of this ice is found in the polar ice caps of Greenland and Antarctica. An additional 15.4% of the Earth's surface is covered by permafrost, which is land with snow depths ranging from a few meters to hundreds of meters. In contrast to this permafrost, the areas covered by seasonal snow and ice change dramatically.(4) It is worth noting that the global climate is directly affected by the state of the cryosphere, due to its role in reflecting a large amount of solar radiation falling on the Earth's surface,(5) in addition to its role in organizing the hydraulic cycle on Earth. Biogeochemical cycles in sea ice and permafrost also influence atmospheric concentrations of carbon dioxide and methane. In addition, icebergs are habitats for many organisms and important nutrients for marine ecosystems.

It is worth noting that the Earth's climate system is a dynamic system that is affected by the interaction between the various sub-systems previously referred to. The processes of this dynamic system take place in the lower layer of Earth's atmosphere, known as the troposphere, in which about 90% of the mass and volume of the gases forming the atmosphere are concentrated.

(4) Cecilia M. Bitz, and Shawn J. Marshall, "Modeling of Cryosphere", *in Encyclopedia of Sustainability Science and Technology* (New York, NY: Springer, 2012): 2761-2780.
(5) Farmer, *Modern Climate Change Science*.

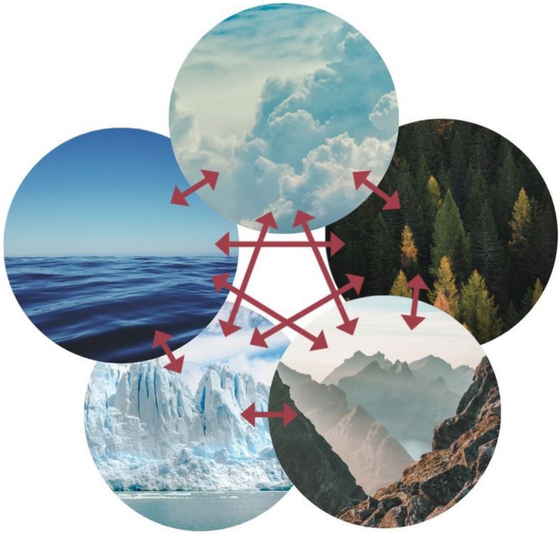

Figure 1.1: Climate sub-systems.
Source: Femkemilene, “The Five Components of the Climate System”, online e-picture, under “Climate System”, *Wikimedia Commons*, https://commons.wikimedia.org/w/index. php?curid=79629050.

1.3 Climate Change and Greenhouse Gases (GHGs)

Human activities over the past two centuries, especially activities related to burning fossil fuels such as energy production, transportation, and industry, led to the emission of large quantities of these gases. This, in turn, led to an increase in their concentrations in the atmosphere, and then accelerated the pace of the global warming mechanism, raising the temperature of the Earth’s atmosphere and the occurrence of climate change. Changes in land use/land cover patterns also contributed; in particular, deforestation in climate change, as these changes led to a reduction in the ability of ecosystems to absorb and stabilize carbon dioxide, as well as a change in the degree of reflection of falling sunlight from the Earth’s surface.[6]

Greenhouse gases include carbon dioxide, methane, nitrous oxides, ozone, chlorofluorocarbons, aerosols, and water vapor. Although water vapor is one of the most common causes of global warming in the atmosphere, it does not remain in the atmosphere for long periods, as it does not mix well in the atmosphere and decreases with precipitation.[7] In the following, we will briefly review the most important greenhouse gases, their sources, and their characteristics.

(6) Colleen Murphy, Paolo Gardoni and Robert McKim, eds., “Risks and Values: New and Interconnected Challenges”, in *Climate Change and Its Impacts: Risks and Inequalities*, Climate Change Management (Cham, Switzerland: Springer, 2018).

(7) *Ibid*.

1.3.1 Carbon Dioxide Gas

Carbon dioxide (CO_2) is a minor component of the Earth's atmosphere. It represents no more than 0.04% (equivalent to 400 parts per million by volume) of the atmosphere, which is a very limited amount. However, it is a very important gas because it is a major part of the gas cycle. Carbon is used by plants for photosynthesis and by animals that consume plants. Carbon dioxide is naturally emitted from various sources such as volcanoes and hot springs.

Many studies related to climate change focus on carbon dioxide gas, as one of the most greenhouse gases that contribute to raising the temperature of the atmosphere and the Earth's surface, not only because of a significant increase in its concentrations in the atmosphere since the Industrial Revolution but also because of its persistence in the atmosphere for long periods of time.

1.3.2 Methane (CH_4)

Methane is one of the most effective greenhouse gases and is present in smaller quantities in the atmosphere compared to carbon dioxide, but its concentration is constantly increasing due to its emission because of thawing permafrost and by methane compounds in shallow marine environments. It is worth noting that methane gas exceeds carbon dioxide by about 21 times in terms of its ability to retain heat rays and re-emit them to the surface of the earth approximately and eventually is converted into carbon dioxide by oxidation. Methane is a hydrocarbon gas that is produced through natural sources and human activities, including the decomposition of waste in sanitary landfills for garbage, agriculture, especially rice.

1.3.3 Nitrous Oxide (N_2O)

Nitrous oxide is one of the most important greenhouse gases due to its long residence time in the atmosphere, which can reach about 120 years, and its ability to absorb and stabilize heat radiation, which is about 310 times that of carbon dioxide (on a per-molecule basis). The increase in the concentration of nitrous oxide gas in the atmosphere has been estimated at about 10% over the past four decades. Nitrous oxide (N_2O) is produced from both natural and human sources. Natural resources include many biological processes in soil and water, particularly microbial activity in tropical rainforests. While the main human sources of nitrous oxide emissions include agricultural soils, animal waste, wastewater treatment processes, burning fossil fuels, and the production of nitric acid and other acids.[(8)]

(8) G. Thomas Farmer, and John Cook, *Climate Change Science: A Modern Synthesis*, vol. 1, *The Physical Climate* (New York, NY: Springer, 2013).

1.3.4 Ozone (O_3)

The presence of ozone in the upper atmosphere, particularly in the stratosphere, is considered a positive thing due to its vital role in preserving life forms on the Earth's surface by absorbing ultraviolet radiation and preventing it from reaching the Earth's surface and thus protecting life on Earth from the sun's harmful ultraviolet rays. Considering other greenhouse gases (carbon dioxide, methane, and nitrous oxide), we find that a continuous increase in tropospheric ozone concentration will transform the entire soil system from a storehouse of these greenhouse gases into a source of emissions of those greenhouse gases.(9)

1.3.5 Chlorofluorocarbons (CFCs)

CFCs are synthetic, entirely man-made, and thus are not produced from natural sources or processes. The long survival time of these compounds is one of the most important advantages that attracted the industry to produce these compounds, which is currently considered one of its main disadvantages, as it exists after being released into the atmosphere for long periods that may reach hundreds of years, as it rises for years in the atmosphere until it finally arrives to the stratosphere, where it erodes the stratospheric ozone layer. In addition to CFCs, Ozone Depleting Substance (ODS) include several different compounds such as Hydrochlorofluorocarbons (HCFCs) and halons, all of which are greenhouse gases. It is customary to exclude these compounds from greenhouse gas inventories because their use is restricted by the Montreal Convention and they are being phased out.(10)

1.3.6 Aerosols

Aerosols are tiny particles suspended in the air that can affect the climate by changing the amount of the sun's energy that is reflected into space. Aerosols can result from natural sources such as volcanoes or from human activities such as burning fossil fuels as well as burning savannas and forests in the tropics.(11) The effect of aerosols on the global warming mechanism varies between positive (lower temperatures) or negative (higher temperatures), and the form of effect varies depending on the type of aerosols. However, the role of aerosols in global warming is generally negligible compared to the role of other greenhouse gases.(12)

(9) Hongxia Wang, Junfeng Zhang and Hong Fang, "Electricity Footprint of China's Industrial Sectors and Its Socioeconomic Drivers", *Resources, Conservation and Recycling* 124 (2017): 98-106, e-article, Science Direct (database). ELSEVIER.

(10) United States Environmental Protection Agency (EPA). Center for Corporate Climate Leadership, *Green House Gas Inventory Guidance: Direct Fugitive Emissions from Refrigeration, Air Conditioning, Fire Suppression, and Industrial Gases* (Washington, DC: EPA, 2023).

(11) J. T. Houghton, G. J. Jenkins and J. J. Ephraums, eds., *Climate Change: The IPCC Scientific Assessment* (Cambridge: Cambridge University, 1990).

(12) S. J. Smith, and T. C. Bond, "Two Hundred Fifty Years of Aerosols and Climate: The End of the Age of Aerosols", *Atmospheric Chemistry and Physics* 14, no. 2 (2014): 537-549, online e-article, European Geosciences Union (database), https://acp.copernicus.org/articles/14/537/2014/#:~:text=While%20aerosols%20have%20had%20a,global%20decrease%20in%20pollutant%20emissions.

1.3.7 Other Trace Gases

Greenhouse gases also include several other rare gases in the atmosphere, which are inert or inactive gases, the most famous of which are argon, neon, helium, krypton, and xenon. Hydrogen is also present in trace amounts in the atmosphere but because it is so light, it disperses into outer space.[13]

1.4 Global Greenhouse Gas Emissions

The concentrations of greenhouse gases in the Earth's atmosphere have increased significantly at the present time compared to pre-industrial levels, as it is estimated that the concentration of carbon dioxide (CO_2) has reached 391 parts per million[14] in 2011, which represents an increase from pre-industrial levels by 40%; while the concentrations of methane (CH_4) and nitrous oxide (N_2O) in the same year were about 1803 and 324 parts per billion (ppb), which represents an increase from pre-industrial levels by 150% and 20% each, respectively.[15]

Regarding the relative distribution of greenhouse gas emissions, carbon dioxide emissions constitute the highest percentage of greenhouse gas emissions worldwide, equivalent to about 81% of the total greenhouse gas emissions in 2017, followed by methane, nitrous oxide, and hydrofluorocarbon gases, at rates of about 11% and 5%, and 2%, for each of them, respectively.

1.4.1 Contribution of Countries to Greenhouse Gas Emissions

Until 2006, the United States of America was the first country in the world in terms of the volume of greenhouse gas emissions, but the volume of emissions from China began to increase little by little until it occupied the first place in the world, surpassing the United States of America. By 2015, the largest countries emitting greenhouse gases (carbon dioxide equivalent) were China, the United States, the European Union, India, Russia, and Japan, respectively, as the combined annual emissions of those countries amounted to about 49.1 gigatons of carbon dioxide equivalent, which represents about 63% of the total greenhouse gas emissions in the world.

As for the average per capita emissions of greenhouse gases (carbon dioxide equivalent), (Figure 1.2). It is noticeable that the average per capita share of greenhouse gas emissions is higher in developed countries compared to developing countries. In this context, it should be noted that despite the expected increase in

(13) Farmer, *Climate Change Science*.

(14) Daniel Huppmann, *et al*., "A New Scenario Resource for Integrated 1.5 C Research", *Nature Climate Change 8* (2018): 1027-1030, online e-article, Nature Portfolio (database), https://www.nature.com/articles/s41558-018-0317-4.

(15) Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2013: The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Thomas F. Stocker, *et al*. (Cambridge: Cambridge University Press, 2013), https://www.ipcc.ch/report/ar5/wg1/.

greenhouse gas emissions significantly faster in developing countries in the future, average per capita emissions of greenhouse gases are expected to remain much higher in developed countries. Therefore, developing countries believe that considering the high average per capita emissions of greenhouse gases in developed countries, there is no need to put an end to their emissions of greenhouse gases.

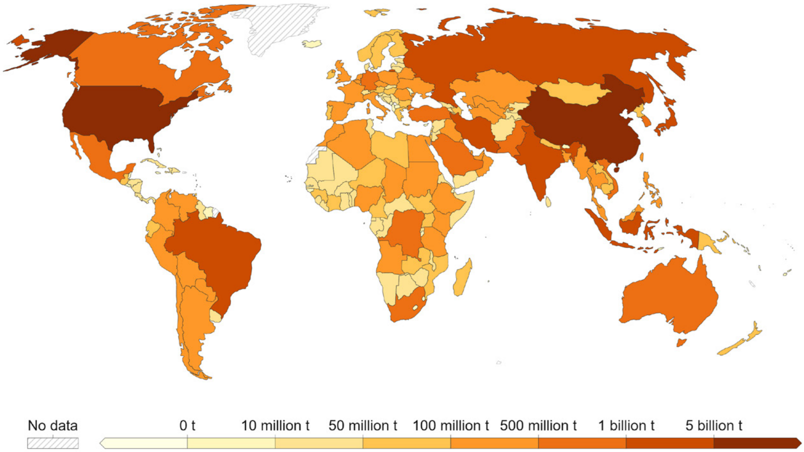

Figure 1.2: GHGs emissions by country.
Source: *Our World in Data.*[16]

1.4.2 Contribution of Economic Sectors to Greenhouse Gas Emissions

The different economic sectors vary among themselves in terms of their contribution to greenhouse gas emissions. This is evident from the estimates made for greenhouse gas emissions in 2010 according to the economic activities issued by them,[17] which indicates the contribution of some economic sectors and not others in large proportions of emissions of greenhouse gases (Figure 1.3) are as follows:

- Generation of electricity and energy: The burning of coal, natural gas, and oil for the purposes of generating electricity and heat is the largest single source of emissions of these gases globally, as these activities contribute about 25% of the total greenhouse gas emissions worldwide.

(16) Hannah Ritchie, Pablo Rosado and Max Roser, "Green House Gas Emissions: Which Countries Emit the Most Greenhouse Gases Each Year? How Do They Compare per Person?" *Our World in Data*, https://ourworldindata.org/greenhouse-gas-emissions.

(17) Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2014: Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Christopher B. Field, *et al*. (Cambridge: Cambridge University Press, 2014), https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-FrontMatterA_FINAL.pdf.

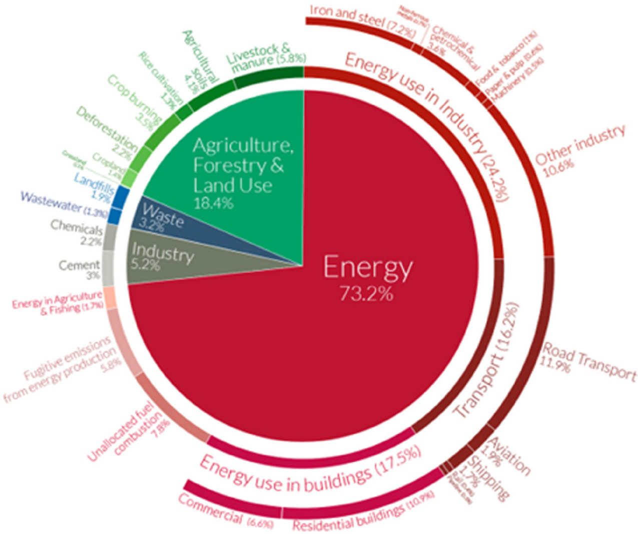

Figure 1.3: GHGs emissions by sector.
Source: *Our World in Data.*(18)

- Industry: Greenhouse gas emissions from industry primarily include fossil fuels that are burned at industrial facility sites for energy production. The emissions of this sector also include emissions from chemical and mineral transformation processes that are not related to energy consumption, as well as emissions from waste management activities. Industrial activities contribute about 21% of global greenhouse gas emissions. It should be noted that the emissions resulting from the use of electricity in the industrial sector, which were generated in the electricity and heat generation sector away from industrial facilities, are excluded and are instead included in the electricity and heat production sector.
- Agriculture, forestry and other land use: Most of the greenhouse gas emissions generated by this sector (crop and livestock farming) are generated by forestry. On the other hand, this estimate does not include the amounts of carbon dioxide that ecosystems sequester (sequester) from the atmosphere in biomass, dead organic matter, and soil, and greenhouse gas emissions from those activities represent about 24% of total greenhouse gas emissions globally.(19)

(18) Hannah Ritchie, Paolo Rosado and Max Roser, "Breakdown of Carbon Dioxide, Methane and Nitrous Oxide Emissions by Sector: How Much Does Electricity, Transport and Land Use Contribute to Different Greenhouse Gas Emissions?" *Our World in Data*, https://ourworldindata.org/emissions-by-sector.

(19) F. N. Tubiello, *et al.*, *Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks*, Working Paper Series ESS/14-20 (Rome: Food and Agriculture Organization (FAO). Statistics Division, 2014), https://www.uncclearn.org/wp-content/uploads/library/fao198.pdf.

- Transportation: Transportation activities result in greenhouse gas emissions as a result of burning fossil fuels in land, rail, air and sea transport, bearing in mind that approximately 95% of the world's transport energy comes from petroleum-derived fuels, most of which are gasoline and diesel. The activities contribute transport accounts for about 14% of global greenhouse gas emissions.
- Residential buildings: Relatively large amounts of greenhouse gases are emitted from buildings as a result of generating energy in buildings and burning fuel for heating or cooking in homes. Greenhouse gas emissions from buildings represent about 6% of the total global greenhouse gas emissions: it should be noted that emissions resulting from the use of electricity in the buildings sector that were generated in the electricity generation and energy away from the buildings sector are excluded and are instead included in the electricity generation sector, electricity and energy.
- Other energy sources: This source includes all greenhouse gas emissions resulting from the energy sector that are not directly related to electricity generation or heat production, such as fuel extraction, refining, processing, and transportation. The emissions from those sources represent about 10% of the total greenhouse gas emissions worldwide.(20)

1.5 The Causes of Climate Change from an Economic Perspective

From an economic point of view, climate change can be explained by the problem of open usufruct rights. In the case of using common natural resources such as water and air, which usufruct rights are usually characterized as open access rights, the decisions of individuals depend on calculating and comparing private benefits. With private costs, which means that individuals do not take into account social benefits and costs when making their decisions, and therefore each of them will try to obtain the maximum net private benefit at the expense of others.

According to economic theory, the economic system based on the market is considered one of the best systems for dealing with resource allocation and utilization effectively in the interest of the individual and society at the same time. However, this requires the availability of a set of conditions and circumstances, including but not limited to:

- The presence of markets for all goods and services.
- These markets are completely competitive (no party can influence the price).
- All parties (producers and consumers) have complete information about current and future prices.
- The existence of private property rights to all resources and goods.

(20) D. Luthi, *et al*., "The Relentless Rise of Carbon Dioxide", *National Aeronautics and Space Administration (NASA). NASA Science*, https://climate.nasa.gov/climate_resources/24/graphic-the-relentless-rise-of-carbon-dioxide/.

- The absence of external influences, whether positive or negative.
- All commodities are private commodities.[21]

However, it is difficult to meet these conditions together,[22] which leads to the failure of the market system to achieve optimal utilization of resources, which is what economists call market failure, and some believe that the phenomenon of climate change is one of the clearest examples of market failures in human history.[23]

Various human activities result in the emission of large amounts of greenhouse gases as by-products of production processes (because of burning fossil fuels for energy production in the industrial sector or raising livestock in the agricultural sector). The emission of large quantities of greenhouse gases into the atmosphere causes fundamental changes in greenhouse gas concentrations and thus climate change, which results in a set of indirect (external) costs for current and future generations.

According to this perspective, climate change can be explained as a result of the failure of the market system that assumes that all commodities are private commodities, as the atmosphere is not a private resource but rather a resource with open usufruct rights, meaning that there are no legal restrictions on its utilization, and therefore any country can release any amount of greenhouse gases in the atmosphere in their own interests, and without the need to pay for doing so, which is what makes countries tend to excessive amounts of emissions they emit.

The failure of the market system is also because greenhouse gas emissions have effects (external costs) that detract from social welfare, which the market system does not take into account when setting prices for the resources used and the goods produced, thus increasing greenhouse gas emissions into the atmosphere.[24]

The failure of the market system as one of the causes of climate change means, on the one hand, that policy interventions are needed to mitigate climate change, and on the other hand, that no single country can take action to mitigate or eliminate the threat of climate change.[25] Although the basis for the solution is known, which is

(21) United Nations Conference on Trade and Development (UNCTAD). Virtual Institute on Trade and Development (Vi), *Teaching Material on Trade: The Environment, and Sustainable Development: Transition to a Low-Carbon Economy* (New York, NY: Vi, 2016).
(22) Todd Sandler, *Global Collective Action* (Cambridge: Cambridge University Press, 2004).
(23) Nicholas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge: Cambridge University Press, 2006).
(24) UNCTAD. Vi, *Teaching Material on Trade.*
(25) *Ibid.*

to reduce greenhouse gas emissions in the atmosphere, the reluctance of countries to adopt this solution is due to the need to take a set of measures that would limit some economic activities to control greenhouse gas emissions from those activities. This is something that countries fear will limit their economic growth opportunities.

1.6 Climate Change Impacts

Global warming will lead to drastic changes in the Earth's climate system that may have severe impacts, either directly or indirectly, on the natural and human ecosystems on Earth. To give a few examples, the agricultural sector, which includes crop cultivation, animal production, forestry, fisheries, and fish farms, is one of the most important sectors that will be affected by climate change including impacts on the productivity of pastoral crops and the spread of weeds and harmful pests. Additionally, there would be changes in the timing of the agricultural seasons, an increase in the water needs of various crops, a shrinking of arable land areas, and a deterioration in its fertility. The rise in global sea levels will also lead to the submergence of agricultural lands in low-lying coastal areas or a reduction in agricultural productivity due to the rise in the level of groundwater and its salinity.

Climate change will also affect the productivity of fisheries and fish farms, as a result of the gradual rise in the Earth's temperature and the associated changes in the marine environments, whether they are physical changes (sea surface and inland water temperature, ocean circulation, wave and storm systems) or chemical changes (level salinity, ocean acidification and lower dissolved oxygen concentrations). In this context, it is expected that these changes will pose a threat to about 25% of the habitats of marine species.

The expected impacts of climate change on urban areas include a rise in temperature, exacerbation of heat waves, erratic rainfall and resulting destructive droughts or floods, devastating hurricanes and associated strong winds and landslides, air pollution, as well as sea level rise and its consequences, it is a threat to many coastal urban areas.(26) These impacts have potentially severe consequences for human health, livelihoods, and material assets, especially for the urban poor, slums, and other marginalized groups.(27)

(26) Walter Leal Filho, *et al*. "Assessing the Impacts of Climate Change in Cities and Their Adaptive Capacity: Towards Transformative Approaches to Climate Change Adaptation and Poverty Reduction in Urban Areas in a Set of Developing Countries", *Science of the Total Environment* 692 (2019): 1175-1190, e-article, Science Direct (database) ELSEVIER.

(27) World Bank Group, *World Bank Group Climate Change Action Plan 2021–2025: Supporting Green, Resilient, and Inclusive Development* (Washington, DC: World Bank, 2021).

Studies indicate that with the rise in the Earth's surface temperature, the intensity of urban heat waves and the accompanying effect of heat stress on the population of those areas is expected to increase. The more frequent occurrence of heat waves will exacerbate urban heat island effects, causing heat-related health problems and potentially increasing air pollution and deaths. The elderly, children and patients are more vulnerable to heat wave-related deaths, and poor households in urban areas are more likely to be affected by heat waves, which limit income opportunities.(28) Also, people in some professions are more vulnerable to this risk, due to their prolonged exposure to high temperatures as a result of the nature of the work they perform.

On the other hand, coastal urban areas are expected to be exposed to sea level rise and the associated risks of coastal flooding, storm floods, and increased rates of beach erosion. These risks will have widespread impacts on the population, property and ecosystems of coastal urban areas, and pose a threat to the livelihoods of coastal residents.(29)

In addition to the impact of climatic conditions on human well-being in general, through the direct effects of those conditions on the distribution of freshwater resources, agricultural activity, and marine ecosystems and their productivity.(30) These climatic conditions are closely related to human health, through their impact on air pollution levels, infectious disease pathogens and their spread, as well as the human sense of comfort.

Climate change affects air quality, safe drinking water supply, adequate food, and safe shelter and are all determinants of human health. In this context, it can be said that climate change affects health through three climatic factors: extreme heat, natural disasters, and the role of each in the spread of infection with some diseases and as causes of deaths.(31)

Any increase in the frequency of extreme weather events such as storms, floods, droughts and hurricanes will have severe, but indirect, impacts on public health through loss of shelter; population displacement; contamination of water supplies; this could lead to an increased risk of epidemics and infectious diseases, including

(28) Armor Revi, *et al*., "Towards Transformative Adaptation in Cities: The IPCC's Fifth Assessment", *Environment and Urbanization* 26 (2014): 11-28, online e-article, Sage Journals (database), https://journals.sagepub.com/doi/full/10.1177/0956247814523539.

(29) *Ibid*.

(30) A. J. McMichael, C. D. Butler and C. Folke, "New Visions for Addressing Sustainability", *Science* 302, no. 5652 (2003):1919-1920, e-article, Science Adviser (database).

(31) Kristie L. Ebi, and Jeremy J. Hess, "Health Risks Due to Climate Change: Inequity in Causes and Consequences", *Health Affairs* 39, no. 12 (2020): 2056-2062, online e-article, Health Affairs (database), https://www.healthaffairs.org/doi/10.1377/hlthaff.2020.01125.

diarrhoeal diseases and respiratory diseases. These extreme weather events may also harm agricultural activities and the production of food crops, thus threatening food security, which will lead to malnutrition. In this context, it is estimated that the potential for food crop yield declines is expected to be higher in developing countries, where 790 million people currently suffer from undernourishment and its attendant consequences on the health and well-being of individuals.(32) This means that climate change threatens food security through its effects on agriculture, food, health, social, demographic, and economic systems, and the depletion of fresh water. The impacts of climate change on crop yields, pests, and food prices and supplies are expected to have significant impacts on sustainable development, inequality, poverty eradication, and the achievement of the Sustainable Development Goals.

This is in addition to the destruction that these extreme weather events may inflict on the infrastructure of health services, which will contribute to the low level of performance of these services and reduce their effectiveness, which will negatively affect public health. These indirect effects will be more pronounced in many regions of the world, particularly in areas with limited resources and high population density.(33)

(32) McMichael, “New Visions for Addressing Sustainability”: 12.
(33) *Ibid*.

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Chapter 2
Climate Impacts on Human Health

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Summary

Climate change has various impacts on environmental systems, which in turn impair human health. These impacts can be either direct or indirect. Heat waves, which cause heat-related illnesses (stroke, exhaustion, cramps, sunburn, rash), are an example of direct impacts that are especially morbid in patients with cardiovascular or respiratory diseases. An indirect impact can be noticed with extreme weather events, i.e., wildfires, floods, and droughts that have catastrophic consequences regarding food security. Moreover, climate change will result in rising sea surface temperatures, diminishing marine fish capacity, and leading to decreased capture and consumption of omega-3-rich fish. This will eventually increase mortality in several populations, particularly those in low- and middle-income countries. Additionally, climate change has increased air pollution, cancer prevalence, and the risk of exposure to toxic substances by increasing the vaporization of chemicals. Weather patterns can also affect pathogen levels in water sources with subsequent contamination of water supply systems with pathogens and related diseases. Furthermore, environmental factors can affect species distribution and density, resulting in new interactions between species and an increased risk of zoonotic development.

2.1 Introduction

There is a direct relationship between climate change and human health. Previously, all pandemics such as the plague, cholera, and tuberculosis were related to colonization, slavery, and inefficient healthcare services. Unfortunately, despite the worldwide advances in medicine and improvements in health services and sanitation, major pandemics and epidemics have already afflicted humanity, such as the 2003– acute respiratory syndrome coronavirus outbreak (SARS-CoV), 2009: swine flu pandemic, 2012: Middle East respiratory syndrome coronavirus outbreak, 2013–2016 Ebola virus disease epidemic in West Africa and 2019 COVID-19 pandemic.[(1), (2)]

(1) Jocelyne Piret, and Guy Boivin, “Pandemics throughout History”, *Frontiers Microbiology* 11 (2020): 631736, online e-article, Frontiers (database), https://www.frontiersin.org/articles/10.3389/fmicb.2020.631736/full.

(2) Rachel E. Baker, *et al*., “Infectious Disease in an Era of Global Change”, *Nature Reviews Microbiology* 20 (2021): 193-205, online e-article, Nature Portfolio (database), https://doi.org/10.1038/s41579-021-00639-z.

These pandemics are due to changes in the climate; these include changes in temperature, precipitation, wind, and daylight duration, as well as elevation of sea level and temperature. Other factors, such as demographic changes, technological changes, and economic development can also influence the spread of infections and toxins all over the world.

Overall mortality and morbidity due to infectious diseases have decreased with the improvement of health care and sanitation, notably for lower respiratory tract infections and diarrhoeal disease. Despite this, the burden of infectious disease in low and lower-middle-income nations remains significant, with high mortality and morbidity linked with neglected tropical diseases, tuberculosis, and malaria.(3)

2.2 Climate Change and Health

We can categorize climate change impacts, exposures, and vulnerabilities (Figure 2.1) into:

2.2.1 Health and Heat-Related Illnesses

Exposure to heat waves leads to heat-related illnesses, for example, heatstroke, heat exhaustion, heat cramps, sunburn, and heat rash. There is a specific concern for patients with cardiovascular or respiratory diseases, as their mortality and morbidity are increased with heat exposure. There is also a change in labor capacity, which has decreased by 4–6% due to changes in temperature.(4) Air pollution is another cause of illness, causing an increase in asthma and allergy patients.(5)

Volatile organic chemicals generated by chemical products contribute to the production of smog. This results in poor air quality that can injure the lungs or exacerbate respiratory illnesses like asthma and Chronic Obstructive Pulmonary Disease (COPD). Unfortunately, warmer temperatures tend to exacerbate the effects of air pollution.(6)

As the primary source of air pollution shifts from vehicles to chemical products, and as the planet gets warmer, the influence of smart product choices on air quality will become significantly higher.(7)

(3) *Ibid*.

(4) Ichiro Kurane, “The Effect of Global Warming on Infectious Diseases”, *Osong Public Health and Research Perspectives* 1, no. 1 (Dec 2010): 4-9, online e-article, Pub Med (database), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3766891/.

(5) Ioannis Manisalidis, *et al*., “Environmental and Health Impacts of Air Pollution: A Review” *Front Public Health 8* (2020): 14, online e-article, Frontiers (database), https://www.frontiersin.org/articles/10.3389/fpubh.2020.00014/full.

(6) *Ibid*.

(7) *Ibid*.

2.2.2 Health and Natural Disaster

A link has been established between natural disastrous' consequences (such as droughts, storms, tracking wildfires, and floods) and an increase in morbidity and accidental death.[(8), (9)]

Climate change disrupts hydrological cycles, causing dry areas to become drier and wet areas to become wetter. Drought intensity, length, and frequency are all influenced by climate change due to shifting rainfall patterns and rising temperatures. Droughts pose several health problems, including threats to drinking water supplies and sanitation, as well as decreased crop and livestock productivity, increased wildfire risk, and the potential for forced migration.[(10), (11)]

Changed precipitation patterns can raise the likelihood of localized flood events, resulting in physical harm, the transmission of infectious illnesses, and mental health consequences. In 2018, Europe, the Eastern Mediterranean region, and Mongolia were all affected by drought episodes. These episodes had an impact on all populated continents and the worldwide land surface area.[(12), (13)]

2.2.3 Climate-Sensitive Infectious Diseases

Environmental factors can modify species distribution and density, resulting in novel interactions between species and an increased risk of zoonotic development. Due to rainfall changes, there is an increase in some diseases such as cholera. Global estimates of cholera show that there are 2.9 million cases of cholera each year, with 95,000 yearly deaths. The best example is observed in Bangladesh, where at least 100,000 cases and approximately 4500 deaths occur each year. In Bangladesh, high and low rainfall, as well as greater temperatures, increase the number of non-cholera diarrhoeal illness cases.[(14)]

Global warming affects the geographical distribution and activity of vectors. For instance, there has been an increase in mosquito and tick-infested areas, as well as an increase in mosquito activity in some locations due to global warming.

(8) Carla Stanke, *et al*., "Health Effects of Drought: A Systematic Review of the Evidence", *PLoS Currents* 5 (2013), online e-article, Pub Med (database), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/.

(9) Weiwei Du, *et al*., "Health Impacts of Floods", *Prehospital and Disaster Medicine* 25, no. 3 (2010): 265-272, online e-article, https://www.cambridge.org/core/journals/prehospital-and-disaster-medicine/article/abs/health-impacts-of-floods/11829B2183F14BF6E8563C37D73E8651.

(10) Stanke, "Health Effects of Drought".

(11) Du, "Health Impacts of Floods": 265-272.

(12) Stanke,"Health Effects of Drought".

(13) Du, "Health Impacts of Floods": 265-272.

(14) Md Taufiqul Islam, John D. Clemens and Firdausi Qadri, "Cholera Control and Prevention in Bangladesh: An Evaluation of the Situation and Solutions", *The Journal of Infectious Diseases* 218, suppl. 3 (2018): S171-S172, online e-article, Oxford Academic (database), https://doi.org/10.1093/infdis/jiy470.

Consequently, global warming induces mosquito-borne infectious diseases, such as dengue fever, malaria, Japanese encephalitis, tick-borne encephalitis, and Lyme disease. Generally, pathogens threaten human populations through contact between humans and animal reservoirs and then through human-to-human transmission. This almost certainly caused the pathogen's geographical range to expand beyond the zone of spillover.(15), (16) For instance, evidence suggests that climatic changes have caused populations of the black flying fox in Australia, a significant Hendra virus reservoir, to migrate 100 kilometers southward in the last 100 years. Hendra virus presumably spread to southern horse populations because of the shifting range, and these horses then infected people.(17) It is worth noting that climate change, whether operating regionally or year-to-year in response to seasonal oscillations, may potentially have an impact on transmission.(18)

2.2.4 Contamination of Water and Foods with Bacteria and Toxins

It is critical to comprehend how weather changes can alter pathogen levels in water supplies, given the overwhelming scientific evidence. Contamination of water sources with disease-causing pathogens is a serious water quality concern around the world. Since pathogen contamination is a major problem that affects practically all sorts of water sources, it is essential that we recognize and try to solve this problem.(19)

Water contamination may be due to inappropriate sewage disposal or weather events. For instance, rainfall has the potential to influence the transmission and spread of infectious organisms, venomous animals, and environmental toxins, while temperature affects their growth and survival. Many epidemics have been triggered by water-borne diseases (such as diarrhoea, gastrointestinal diseases) caused by various bacteria, viruses, and protozoa. Typically, waterborne infections affect millions of people in impoverished nations like Africa.(20), (21)

(15) World Health Organization (WHO), *Quality Criteria for Health National Adaptation Plans* (Geneva: WHO, 2021), https://www.who.int/publications/i/item/quality-criteria-health-national-adaptation-plans.

(16) Jessica Colarossi, "Ticks and Mosquitoes, Infectious Disease Carriers, Are Expanding Their Range", *The Brink*, https://www.bu.edu/articles/2020/ticks-mosquitoes-infectious-disease-carriers-expanding-their-range/.

(17) Grit Schubert, *et al*., "The African Network for Improved Diagnostics, Epidemiology and Management of Common Infectious Agents", *BMC Infectious Diseases* 21, no. 539 (2021): 1-10, online e-article, Springer Nature (database), https://doi.org/10.1186/s12879-021-06238-w.

(18) WHO, *Quality Criteria*.

(19) Len Ritter, *et al*., "Sources, Pathways, and Relative Risks of Contaminants in Surface Water and Groundwater: A Perspective Prepared for the Walkerton Inquiry", *Toxicol Environ Health A* 65, no. 1 (2002): 1-142, online-e-article, Pub Med (database), https://pubmed.ncbi.nlm.nih.gov/11809004/.

(20) Nick Watts, *et al*., "The 2020 Report of the Lancet Countdown on Health and Climate Change: Responding to Converging Crises", *The Lancet* 397, no. 10269 (2021): 129-170, online e-article, The Lancet (database), https://www.thelancet.com/article/S0140-6736(20)32290-X/fulltext.

(21) GBD 2017 Diet Collaborators, "Health Effects of Dietary Risks in 195 Countries, 1990-2017: A Systematic Analysis for the Global Burden of Disease Study 2017", *The Lancet* 393, no. 10184 (2019): 1958-1972, online e-article, The Lancet (database), https://www.thelancet.com/article/S0140-6736(19)30041-8/fulltext.

Diarrhoea is considered a major cause of death in children under the age of five, accounting for more than 525,000 fatalities each year. Diarrhoea can deplete the body's supply of water and salts, resulting in significant consequences. In the past, acute dehydration and fluid loss were the most common causes of diarrhoeal mortality. Other causes of diarrhoea-related death, such as septic bacterial infections, are expected to account for an increasing percentage of all diarrhoea-related deaths.(22)

Future water demands must account for food, energy, and ecosystem requirements. This is carried out through long-term planning and must incorporate expanding water storage infrastructures (such as dams). Unfortunately, such new structures have the potential to degrade water quality and increase public health hazards. This is not ideal as improving the quality of water can assist in reducing the world's illness burden by about 4%.(23)

Contamination of drinking water could be due to pathogenic contamination and nonpathogenic (toxic) contaminants. It is the most significant health risk to humans. These pollutants could be both natural and man-made. Nitrogen, bleach, salts, pesticides, metals, bacterial toxins, and human or animal medications are examples of chemical pollutants. Elements with an uneven number of protons and neutrons produce unstable atoms that can generate ionizing radiation. Accordingly, these elements are known as radioactive pollutants. Cesium, plutonium, and uranium are examples of radioactive pollutants.(24)

2.2.5 Food Security and Undernutrition

Climate change threatens to increase the worldwide number of undernourished people due to climate shocks, increasing temperatures, and ground-level ozone influencing crop yields, in addition to coral bleaching and sea surface temperature influencing marine food security. These consequences will be felt inequitably and disproportionately affecting countries and populations already suffering from poverty and starvation and increasing existing inequities. These variations are tracked by two indicators, which track changes in crop production potential and sea surface temperature.(25)

(22) Watts, "The 2020 Report of the Lancet Countdown": 129-170.

(23) *Ibid*.

(24) Manuel Barange, *et al*., eds., *Impact of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options* (Rome: Food and Agriculture Organization (FAO), 2018). https://www.fao.org/3/i9705en/i9705en.pdf.

(25) "Food Balances (2010)", *Food and Agriculture Organization of the United Nations*, http://www.fao.org/faostat/en/#data/FBS.

A considerable majority of the world, particularly in low- and middle-income countries, relies heavily on fish for protein. Fish-based omega-3 fatty acids are also vital in reducing the occurrence of cardiovascular diseases. To illustrate, in 2017, 14 million worldwide deaths were related to diets poor in seafood omega-3 fatty acids. Similarly, rising sea surface temperatures because of climate variation diminish the capacity of marine fish through a variety of causes. These causes include decreased oxygen content and coral reef bleaching, which decrease overall fish capture, putting the populations at risk.(26), (27), (28)

2.2.6 The Risk of Exposure to Toxic Substances

The temperature has an impact on how compounds behave, for example increasing vaporization. Higher temperatures cause certain substances to evaporate and enter our lungs.(29)

- Chemicals: Disastrous climate-related occurrences such as fires, hurricanes, and other natural disasters can discharge harmful chemicals, resulting in air pollution. Temperatures can determine the behavior of chemicals, where higher temperatures increase our exposure to harmful compounds.(30)
- Temperature air pollution: Volatile organic molecules emitted by chemical materials lead to the production of smog. This results in poor air quality that can harm the lungs or exacerbate respiratory diseases like asthma and COPD.(31), (32), (33)

(26) Pamela D. Noyes, and Sean C. Lema, “Forecasting the Impacts of Chemical Pollution and Climate Change Interactions on the Health of Wildlife”, *Current Zoology* 61, no. 4 (Aug 2015): 669-689, online e-article, Oxford Academic (database), https://doi.org/10.1093/czoolo/61.4.669.

(27) Caroline C. Ummenhofer, and Gerald A. Meehl, “Extreme Weather and Climate Events with Ecological Relevance: A Review”, *Philosophical Transactions of the Royal Society B: Biological Sciences* 372, no. 1723 (Jun 2017): 20160135, online e-article, The Royal Society (database), https://doi.org/10.1098/rstb.2016.0135.

(28) Corwin M. Zigler, *et al*., “Impact of National Ambient Air Quality Standards Nonattainment Designations on Particulate Pollution and Health”, *Epidemiology* 29, no. 2 (Mar 2018): 165-174, online e-article, https://doi.org/10.1097/EDE.0000000000000777.

(29) “Volatile Organic Compounds (VOCs)”, *Minnesota Pollution Control Agency*, https://www.pca.state.mn.us/air/volatile-organic-compounds-vocs.

(30) Brian C. McDonald, *et al*., “Volatile Chemical Products Emerging as Largest Petrochemical Source of Urban Organic Emissions”, *Science* 359, no. 6377 (Feb 2018): 760-764, online e-article, Science Adviser (database), |https://doi.org/10.1126/science.aaq0524.

(31) European Environmental Agency (EEA), *Climate Change, Impacts and Vulnerability in Europe 2012: An Indicator-Based Report*, EEA Report 12/2012 (Copenhagen: EEA, 2012), https://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012.

(32) Alaa Omran, “Egypt Sounds Alarm Over Toxic Puffer Fish”, *Al-Monitor*, https://www.al-monitor.com/originals/2020/12/egypt-warning-puffer-fish-toxic-fishing-sale-poisoning.html.

(33) Geoffrey K. Isbister and Matthew C. Kiernan, “Neurotoxic Marine Poisoning”, *Lancet Neurology* 4, no. 4 (2005): 219-228, e-article, The Lancet (database).

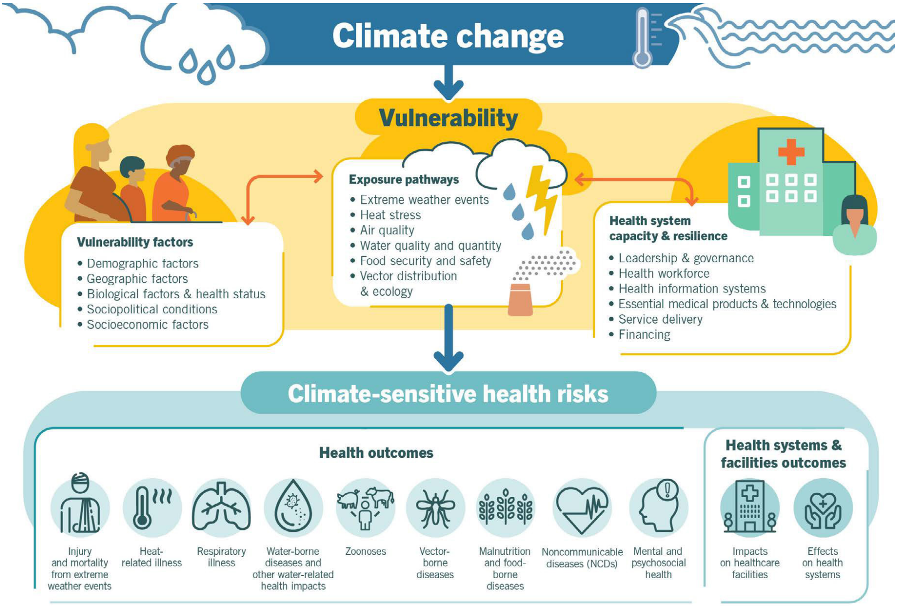

Figure 2.1: Major health risk with climate change (after permission of WHO 388175).[34]

2.2.7 Marine and Food Safety

The physical and biological makeup of seas will be drastically altered by the effects of climate change, such as ocean acidification, rising sea surface temperatures, and alterations in currents and wind patterns. Temperature and ocean circulation changes can alter the geographic distribution of fish. A rise in sea temperature may allow alien organisms to spread into areas where they previously could not exist.[35]

Acidification of the ocean, for example, will influence calcium carbonate-secreting species. These changes will have unavoidable effects on coastal and marine ecosystems, with huge socioeconomic implications for many places.[36]

(34) WHO, *Quality Criteria*.

(35) Yedidia Bentur, *et al*., "The Clinical Effects of the Venomous Lessepsian Migrant Fish Plotosus lineatus (Thunberg, 1787) in the Southeastern Mediterranean Sea", *Clinical Toxicology* 56, no. 5 (2018): 327-331, e-article, PubMed (database), National Library of Medicine.

(36) *Ibid*.

a) An Example of the Effect of Climate Change on Marine Life and Food Safety in Egypt

Rabbitfish are endemic to warm-water tropical locations, such as the Red Sea. However, due to the increase in water temperature, it entered the Mediterranean through the Suez Canal(37) (Figure 2.2).

The most prevalent fish-borne seafood poisoning is ciguatera poisoning. Ciguatoxin, the causative agent, is a heat-stable ester complex that is concentrated in fish that eat poisonous dinoflagellates. A mix of gastrointestinal and neurologic symptoms are the most typical clinical presentations. Seizures and respiratory paralysis are possible side effects of severe poisoning.(38)

Figure 2.2: Rabbitfish.(39)

b) An Example of the Effect of Climate Change on Spiders and Snakes in Egypt

A common poisoning agent in tropical and subtropical areas is snake and scorpion poisoning. “A massive scorpion swarm in southern Egypt left three dead and 500 hospitalized after heavy storms on 13 November 2021”.(40) The common venomous snakes of Egypt are the Cobra (Black Desert, Egyptian, Red Spitting), Field’s Horned Viper, Sahara Sand Viper, Indian Saw-scaled Viper, Egyptian Carpet Viper, and Painted Saw-scaled Viper.(41)

(37) “More than 500 Hospitalized from Scorpion Stings after Storm in Egypt”, *NBC News*, https://www.nbcnews.com/news/world/500-hospitalized-scorpion-stings-storm-egypt-rcna5659.

(38) “The Most Venomous Snakes of Egypt”, *The World Atlas*, www.worldatlas.com/articles/the-most-venomous-snakes-of-egypt.html.

(39) Marina Hyde, “La Palma’s Volcanic Headache: What to Do with all the Lava and Ash”, *The Guardian*, https://www.theguardian.com/world/2022/jan/14/la-palma-volcano-lava-ash-island.

(40) Sareh Dortaj, “The Toxic Components and the Clinical Uses of Snake Venom: A Review”, *Asia Pacific Journal of Medical Toxicology (APJMT)* 10, no. 3 (Sep 2021): 107-112, online-e-article, https://apjmt.mums.ac.ir/article_18823_3ade5d15c0397b8cb625a2efd4ae5f12.pdf.

(41) Wesam M. Salama and Khadiga M. Sharshar, “Surveillance Study on Scorpion Species in Egypt and Comparison of Their Crude Venom Protein Profiles”, *The Journal of Basic and Applied Zoology* 66, no. 2 (2013): 76-86, online-e-article, Science Direct (database), ELSEVIER, https://doi.org/10.1016/j.jobaz.2013.10.003.

Snake venoms are complex mixtures consisting of enzymatic components, such as proteolytic enzymes (serine protease and metalloproteases), and non-enzymatic components, such as Cysteine-Rich Secretory Proteins (CRISPs), amines, lipids, nucleotides, and carbohydrates. Inorganic cations are also present in venoms and are thought to act as cofactors. They include sodium, calcium, potassium, magnesium, and zinc.(42)

In Egypt, there are eight species of scorpion. The first is *Scorpio maurus palmatus*, which is related to the family *Scorpionidae*, and the rest belong to the family *Buthidae*. Four of them fall into the genus *Androctonus* namely: *Androctonus*, which is very rare in Egypt, *Androctonus australis*, *Androctonus bicolor*, and *Androctonus amoreuxi*.(43)

The bites and stings usually increase in certain seasons with regional variation. In APC, bites and stings represented 2.1% of admitted cases in 2017, and 1.99% of admitted cases in 2019.(44)

Amputations, post-traumatic stress disorder, blindness, maternal and fetal loss, contractures, persistent infections, and malignant ulcers are among the chronic morbidities, disabilities, and psychological consequences of snakebite envenomation.(45)

Bites and stings produce local tissue damage and myonecrosis. Blood vessel integrity is also harmed, which leads to the deterioration of micro vessel mechanical stability. Additionally, envenomation produces systemic manifestations, such as neurotoxicity, acute kidney injury, rhabdomyolysis, cardiovascular and homeostatic disturbances.(46)

2.3 Conclusion

The increase in the average global temperature has a great impact on vulnerable communities, with increased morbidity and mortality rates. The current temperature is suitable for the transmission of several infectious, such as dengue fever and malaria. At the same time, food security and undernutrition will be magnified by

(42) Maha Ghanem, Salma Abdullah Mohammed and Mona Hamdy, "Assessment of Resources and Services Utilization of Alexandria Poison Center", *Asian Journal of Biomedical and Pharmaceutical Sciences* 8 (2018): 21, online e-article, Allied Academics (database), https://www.alliedacademies.org/conference-abstracts-files/2249-622X-C2-005-001.pdf.

(43) José María Gutiérrez, *et al*., "Snakebite Envenoming", *Nature Reviews Disease Primers* 3, no. 17063 (2017): 1-21, online e-article, Nature Portfolio (database), https://doi.org/10.1038/nrdp.2017.63.

(44) Hyde, "La Palma's Volcanic Headache".

(45) Ghanem, Mohammed and Hamdy, "Assessment of Resources and Services".

(46) "Volcanic Gases Can Be Harmful to Health, Vegetation and Infrastructure", *Science for Changing World (USGS)*, https://www.usgs.gov/programs/VHP/volcanic-gases-can-be-harmful-health-vegetation-and-infrastructure.

the increased incidence of droughts and floods. Land erosion, deforestation, as well as other human activities (agriculture, skiing) contribute to the problem. Soiling of water, either due to pathogenic or nonpathogenic causes, exacerbates the impact on human health. Air pollution also causes deterioration of the health of certain populations, especially those with respiratory disorders. The public health and financial effects of climate change will be worse if governments and people stay idle. As such, strong and long-term measures to safeguard and reconstruct local communities and the national economy will become absolutely necessary.

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Chapter 3
Biodiversity, Climate Change, and Ecological Restoration

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Abstract

Among the biggest environmental threats that the Earth faces today are biodiversity loss and climate change. Land degradation with climate change phenomena altered habitats causing losses in biodiversity. Greenhouse Gases (GHGs) increased Earth surface temperature, and many species must either adapt or migrate to more favorable areas to survive. Losses in biodiversity include degradation of ecosystems, and species migration or extinction. This has been exacerbated in arid regions due to harsh climatic conditions that increase extreme weather events, dust storms, and sand encroachment into vulnerable areas. The United Nations declared the decade 2020–2030, the decade for ecological restoration. Ecological restoration measures can halt and reduce land degradation and species losses. At a national level, strategic thinking for long-term biodiversity conservation, ecological restoration, and GHGs control are appropriate integrated approaches. A strategic plan for climate mitigation and adaptation in the Arab region including vulnerable ecosystem restoration/ rehabilitation, as well as remediating contaminated soils is recommended. Research on forecast modeling for climate change, key species monitoring, adaptation and mitigation measures, long-term impacts on climate change, and pollution-related issues in soils and water need to be applied in the region with some support.

3.1 Introduction

Biodiversity is "the variability within and among living organisms and the systems they inhabit".(2) The rate of biodiversity loss has been increasing at an unprecedented rate due to many human and natural factors. Global efforts during the United Nations Decade on Biodiversity 2011–2020 have not been sufficient to meet the Aichi Biodiversity Targets established in 2010 to halt biodiversity loss.(3) The Convention on Biological Diversity (CBD) stressed the need for maintenance of

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(2) Secretariat of the Convention on Biological Diversity, *Convention on Biological Diversity: Text and Annexes* (Montreal: Secretariat of the Convention on Biological Diversity, 2011), https://www.cbd.int/doc/legal/cbd-en.pdf.

(3) Secretariat of the Convention on Biological *Diversity, Global Biodiversity Outlook* 5 (Montreal: Secretariat of the Convention on Biological Diversity, 2020), https://www.cbd.int/gbo/gbo5/publication/gbo-5-en.pdf.

biodiversity and the immediate and long-term changes that are required to address threats to biodiversity. Natural phenomena and climate change are among the threats that face biodiversity.

Climate change constitutes three main variables: elevated carbon dioxide (CO_2), altered rainfall patterns, and temperature ranges. Since 2011, concentrations of GHGs have continued to increase in the atmosphere, reaching annual averages of 410 ppm for CO_2, 1866 ppb for methane (CH_4), and 332 ppb for nitrous oxide (N_2O) in 2019.(4) Results of temperature rise predicted dramatic alterations in ecosystems such as salinity rise,(5) rise in seawater level, drought in arid and semi-arid regions as well as extreme weather conditions.

Climate change refers to long-term shifts in temperatures and weather patterns. These shifts may be natural, but since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels, which produces "heat-trapping gases" (GHGs). There is a need for information on the impacts of climate change on biodiversity. It is also critical to analyze its possible benefits and risks to biodiversity and ecosystem services.

The biodiversity of arid regions, such as Kuwait, is under severe stress due to natural and anthropogenic factors. This region is also threatened by global warming phenomena. More severe and harsh climatic conditions will cause an increase in the formation of sand dunes, sand encroachment, and extreme dust storms. Drought will cause more water demand for local consumption and irrigation. The sea water temperature increase would affect the spawning period of fish and shrimp and will cause migration of fish to other more suitable areas. This will severely impact the fish industry in Kuwait and the region. Losses in plant cover will be due to sand encroachment or erratic rainfall periods causing runoff and flooding. Soil salinity has been indicated to increase in arid regions with less rainfall for the last three decades.(6)

(4) Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2021).

(5) Anastasia Anderson, *et al*., "Monitoring of Genetic Diversity: Guidelines Focusing on Species and Population Selection", *Molecular Biology* 31, no. 24 (2022): 6422-6439, online e-article. PubMed Central (database) National Library of Medicine, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10091952/.

(6) Bannari Abdou Abderrazak and Zahraa M. Al-Ali, "Assessing Climate Change Impact on Soil Salinity Dynamics between 1987-2017 in Arid Landscape Using Landsat TM, ETM+ and OLI Data", *Remote Sensing* 12, no. 17 (2020): 2-32, online e-article, Research Gate (database), https://www.researchgate.net/publication/343695599_Assessing_Climate_Change_Impact_on_Soil_Salinity_Dynamics_between_1987-.

The United Nations declared the decade of ecological restoration in the period 2020–2030. It aims to prevent, halt, and reverse the degradation of ecosystems on every continent and in every ocean. It can help to end poverty, combat climate change, and prevent mass extinction. The UN called on everyone to plan a part of the ecosystem restoration.

There is a need to develop a strategic plan for climate change mitigation and adaptation in the region including ecosystem restoration/rehabilitation. Specific elements of the plan would include research for the identification of vulnerable species, conducting modeling research to inform conservation programs, monitoring key species, ex-situ conservation using living collection and ensuring representation in conservation collection, in-situ conservation and increase in protected areas, restoration of degraded ecosystems, policies issuing, adaptation and mitigation measures, education and public awareness programs, as well as networking and sharing knowledge.

3.2 Implications of Climate Change on Biodiversity

As per UN records, biodiversity is threatened by climate change causing a large number of species over 50 to 100 years to either need to migrate rapidly to keep up with changing conditions, to adapt locally to such changes or to face extinction.(7) Forecasts predict that 17–35% of species on Earth will become extinct in the next 100 years. Climate change also has impacts at ecosystem scales (marine and terrestrial). It will affect all ecosystem processes but at different rates, magnitude, and directions.(8) Flooding, sea level rise and changes in temperature will impact ecosystem boundaries causing some ecosystems to expand while others will become smaller. Habitats will change as rainfall and temperatures change and some species will not be able to keep up leading to a sharp increase in extinction rates.(9) Species extinctions; expansion or contraction of species ranges (migration); changes in species compositions and interactions (adaptation); changes in resource availability; spread of diseases to new ranges; changes in the characteristics of protected areas; changes in the resilience of ecosystems. It is expected, thus, that as the climate changes in the future, there will be a disruption of natural communities and the extinction of populations and species.

(7) Secretariat of the Convention on Biological Diversity, *Global Biodiversity Outlook* 5.

(8) Botanic Gardens Conservation International (BGCI), *Plants for Planet: The Work of Botanic Gardens Conservation International in 2008* (Surrey, UK: BGCI, 2008), https://www.bgci.org/wp/wp-content/uploads/2019/04/2008%20annual%20report%20and%20accounts.pdf.

(9) Hannah Reid and Krystyna Swiderska, "Biodiversity, Climate Change and Poverty: Exploring the Links: An IIED Briefing", *International Institute for Environment and Development (IIED)*, https://www.iied.org/sites/default/files/pdfs/migrate/17034IIED.pdf.

3.3 Vulnerability of the Arid Region

Many of the countries that will be at risk from climate change lie in arid regions (such as drought-prone sub-Saharan Africa). The people in these areas depend mainly on climate-sensitive sectors and natural resources. These include agriculture, fishing, water provision, grazing, timber, and non-timber forest products, such as food, medicine, tools, fuel, fodder, and construction material.(10) The dependence on these resources means the impact of climate and their environmental changes on biodiversity and ecosystem services poses a real threat to the livelihood, food security, and health of the poor.(11) Simulation models predict that "dryland biomes" such as savannahs, grasslands, and Mediterranean ecosystems will be among the biomes experiencing the largest biodiversity change and will be affected significantly by the combination of land use change and climate change. Water availability for agriculture and food security. Increased demand for irrigation due to increases in temperature and decreases in precipitation over time, the case study of Lebanon:(12) An integrated mapping methodology for the vulnerability assessment combined indicators was developed in 2019 for Lebanon. Results indicated the following: up to 14% of the study area is projected to exhibit high vulnerability compared to the rest of the country, areas with the highest vulnerability, designated as hotspots, include Al Beqaa Valley and other areas, and most croplands (84%) project moderate vulnerability with remaining areas suggesting low vulnerability. Extreme events in river basins: A case study of three river basins in the Arab Region: Nahr el Kabir River shared between Lebanon and the Syrian Arab Republic; the Wadi Diqah River basin in Oman; and the Medjerda River basin shared between Algeria and Tunisia.(13) For each basin changes under two different emission scenarios (RCP 4.5 and RCP 8.5) showed extreme temperature and precipitation indices, extreme drought events, and extreme flood events. All land areas will become warmer and dryer (higher temperatures and less precipitation). Sea surface temperature in the Arabian Gulf has been steadily increasing at a rate of 0.6°C per decade. Increase in sandstorms imposing respiratory diseases, and road injury. Coastal areas and islands in the Gulf, such as Boubyan Island in Kuwait, will be adversely impacted by rising sea levels.(14)

(10) Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), and United Nations Economic and Social Commission for Western Asia (ESCWA), *Impact of Climate Change on Extreme Events in Selected Basins in the Arab Region* (Damascus: ACSAD; Beirut: ESCWA, 2018), https://riccar.org/sites/default/files/2018-07/RICCAR-Extreme-Events-online_0.pdf.

(11) Anderson, "Monitoring of Genetic Diversity": 6422-6439.

(12) Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), Ministry of Agriculture in Lebanon (MoAg), National Council for Scientific Research (CNRS) and United Nations Economic and Social Commission for Western Asia (ESCWA), *Integrated Vulnerability Assessment Application on the Lebanese Agricultural Sector: Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region* (Beirut: The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR), 2019), https://riccar.org/sites/default/files/2020-01/VA%20Application%20on%20the%20Lebanese%20Agricultural%20Sector.pdf.

(13) ACSAD and ESCWA, *Impact of Climate Change*.

(14) Samira Omar Asem, and Waleed W. Roy, "Biodiversity and Climate Change in Kuwait", *International Journal of Climate Change Strategies and Management* 2, no. 1 (2010): 68-83, online e-article, Emerald Insights (database), https://doi.org/10.1108/17568691011020265.

3.4 Mitigation and Adaptation Measures

Most countries are committed to the UN Framework Convention on Climate Change (UNFCCC), the Sustainable Development Goals (SDG-13), Kyoto Protocol to UN, UN Convention to Control Desertification, CBD, and the Convention on the International Trade in Endangered Species. In the case of Kuwait, actions included both administrative and institutional actions and technology development.

Various causes of action could reduce the rate of biodiversity loss (Figure 3.1). This Figure shows that trends in biodiversity under "business as usual" will cause biodiversity decline in time, however, integrated actions such as enhanced conservation and restoration of ecosystems, climate change mitigation, actions on altering pollution and invasive alien species, as well as controlling overexploitation of resources while producing sustainable products, goods, and services and reducing consumption and waste, all combined together will lead to improving the status of biodiversity in time. However, none of the actions alone or any partial combination of actions can lead to a better curve of biodiversity loss. However, the outcome of each action will enhance the other to a better condition for biodiversity to prevail.

In arid regions such as Kuwait, some actions have been undertaken to reduce the effects of biodiversity losses due to climate change. These actions include the following: the action on reducing GHG emissions required the development of GHGs Inventory and Mitigation Action Plan, the Air Quality Monitoring Department at Kuwait Environmental Public Authority (KEPA), the National Committee on Ozone and Climate Change, and three Task Forces (NTF, GTF, CIVATF) and reporting to the National Project Coordinator for Climate Change at KEPA. A more challenging action is to diversify the economy to reduce the country's dependence on oil revenues (New Kuwait) and to improve the oil sector for clean and sustainable energy production (Al-Zour refinery project, the Bio-fuel project, and the Olefins III and Aromatics II).[15] Establishment of renewable energy parks (Shegaya Park) for solar and wind energy (Kuwait Vision on renewable energy is to reach 15% of energy production by 2030, SDG7). Improvement in the transportation network, maritime transport (Mubarak Al Kabeer Port), and air transport (Terminal 2). Development of Food Security Investment Strategy and application of smart farming technology. Afforestation action plan to increase greenbelts and green areas. Develop and maintain protected areas to conserve biodiversity and control land use. Restore and remediated degraded ecosystems under the Kuwait Environmental Remediation Program (KERP) funded by the United Nations Compensation Commission (UNCC). Increasing efficiency of water production and use, waste management, and recycling projects.

(15) Environmental Public Authority, *First Biennial Update Report of the State of Kuwait: Submitted to the United Nations Framework Convention on Climate Change* (Kuwait: Environmental Public Authority, 2019), https://unfccc.int/sites/default/files/resource/State%20of%20Kuwait%20-%20BUR.pdf.

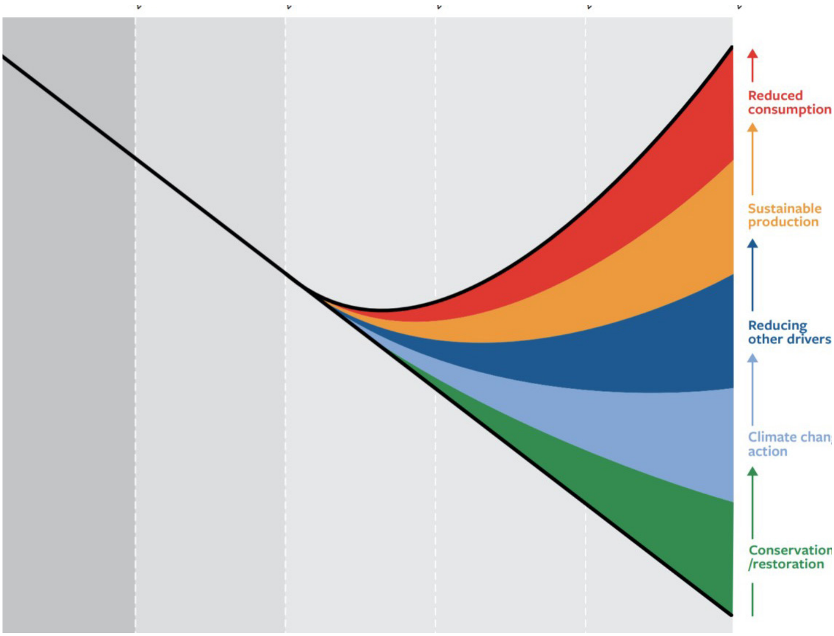

Figure 3.1: A portfolio of actions to reduce loss and restore biodiversity.(16)

"Trends in biodiversity (various metrics, left axis) have been declining and are projected to continue to do so under business-as-usual scenarios (trend line). Various areas of action could reduce the rate of biodiversity decline, and the full portfolio of actions, in combination, could halt and reverse the decline (bend the curve), potentially leading to net biodiversity gains after 2030. These are, from bottom to top: (1) Enhanced conservation and restoration of ecosystems; (2) Climate change mitigation; (3) Action on pollution, invasive alien species and overexploitation; (4) More sustainable production of goods and services, especially food; and (5) Reduced consumption and waste. However, none of the areas of action alone, nor in partial combinations, can bend the curve of biodiversity loss. Moreover, the effectiveness of each area of action is enhanced by the other areas (see Part III of the full report for discussion)".(17)

(16) Secretariat of Convention Biological Diversity, Global Biodiversity Outlooks.

(17) *Ibid*.

3.5 Ecosystem Restoration

The United Nations Development Programme (UNDP) reported that unsustainable consumption and production patterns in the world with increasing population growth and poverty will put our Earth at risk leading to a deterioration in planetary health.[18] Action is needed to conserve and restore damaged ecosystems for biodiversity to reduce losses (Figure 3.1).

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. It aims to recreate, initiate, or accelerate the recovery of an ecosystem that has been disturbed/degraded. Disturbances are environmental changes that alter ecosystem structure and function (such as deforestation, grazing, floods, fire, etc.). Ecological restoration when implemented effectively and sustainably contributes to protecting biodiversity and human well-being, as well as mitigating climate change.[19] The United Nations declared the decade 2020–2030, the decade for Ecological Restoration.

While many natural and anthropogenic factors impact ecosystems and biodiversity, war damages on terrestrial and environmental ecosystems can be devastating and irreversible if no action to restore them is taken. In the case of the environmental damages in Kuwait, the explosion of oil wells is a good example of what aggression against the environment can do. About 800 oil wells were detonated causing massive oil pollution on land and sea. Kuwait had to remediate about 26 million cubic meters of contaminated soil. Thousands of acres of damaged land due to pollution and military activities with millions of munitions and mines left on land needed immediate restoration and remediation. The United Nations Compensation Commission (UNCC) awarded Kuwait about 2.9 billion dollars to mitigate and remediate the damaged ecosystems.

3.6 Monitoring and Assessment

One of the main challenges to the conservation of biodiversity is monitoring.[20] Genetic diversity needs to be monitored regularly to understand changes in species or populations. It also provides information on species under threat of extinction due to alternation in habitats or ecosystems and supports decision-makers in choosing which actions to undertake to mitigate losses. The development of a Decision Support Tool for habitat conservation was conducted by Kuwait Institute

(18) UN Environment, *Global Environmental Outlook* 6 (Kenya: United Nations Development Programme (UNDP), 2019).

(19) George D. Gann, *et al*., "International Principles and Standards for the Practice of Ecological Restoration. Second Edition", *Restoration Ecology* 27, no. S1 (Sep 2019): S1-S46, online e-article, Wiley Online Library (database), Wiley, https://onlinelibrary.wiley.com/doi/10.1111/rec.13035.

(20) Anderson, "Monitoring of Genetic Diversity": 6422-6439.

for Scientific Research (KISR) and provided a system for the development of a GIS Decision Support Tool for data analysis and synthesis.[21] Survey and remote sensing techniques are used to monitor climate change; and the impact of pollution, and to evaluate the efficiency of ecological restoration measures. Scenarios on climate change models and projections are developed by scientists to recommend mitigation actions on climate change.[22]

3.7 Conclusion

Biodiversity is threatened by climate change and a large number of species over 50 years to 100 years will either need to migrate, adapt locally to such changes, or to face extinction. Concentrations of GHG have continued to increase in the atmosphere despite the travel ban and economic slowdown during the COVID-19 pandemic year (2020). The Arid Regions are especially vulnerable to climate change phenomena and action is needed to halt ecosystem degradation and biodiversity losses.

Numerous international, regional, and national organizations/institutions are taking necessary actions to combat climate change. The key point here is to reduce GHG emissions to keep the global temperature rise below 2 degrees Celsius above pre-industrial levels (SDG-13 Paris Agreement 2015). The Glasgow Climate Change Conference (COP26) and the United Nations Climate Change Conference held October/November 2021 called for clean energy infrastructure and the adoption of technologies for a net-zero energy system by 2050.

The UN Decade on Ecosystem Restoration (2021–2030) aims to prevent, halt, and reverse the degradation of ecosystems on every continent and in every ocean. It can help end poverty, combat climate change, and prevent mass extinction. Countries must implement policies and strategies for specific sectors to reduce emissions, to restore degraded ecosystems to halt biodiversity loss, and mitigate climate change impacts. Research on forecast modeling for climate change, key species monitoring, adaptation and mitigation measures, long-term impacts on climate change, and pollution-related issues in soils and water need to be applied in the region with support.

(21) Waleed Roy, *Development of Atlas and Decision Support Tool for the Terrestrial Biodiversity of Kuwait: Final Report* (Kuwait: Kuwait Institute for Scientific Research (KISR), 2013), http://kdr.kisr.edu.kw/en/AdvancedSearch?center=Environment%20and%20Life%20Sciences%20Research%20Center&fprojectTitle=Development%20of%20a%20Decision%20Support%20Tool%20for%20the%20Conservation%20of%20Terrestrial%20Biodiversity%20of%20Kuwait.

(22) Pragya Nema, Sameer Nema and Priyanka Roy, "An Overview of Global Climate Changing in Current Scenario and Mitigation Action", *Renewable and Sustainable Energy Reviews* 16 no. 4 (May 2012): 2329-2336, e-article. Science Direct (database), ELSEVIER.

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Roy, Waleed. *Development of Atlas and Decision Support Tool for the Terrestrial Biodiversity of Kuwait: Final Report*. Kuwait: Kuwait Institute for Scientific Research (KISR), 2013. http://kdr.kisr.edu.kw/en/AdvancedSearch?center=Environment%20and%20Life%20Sciences%20Research%20Center&fprojectTitle=Development%20of%20a%20Decision%20Support%20Tool%20for%20the%20Conservation%20of%20Terrestrial%20Biodiversity%20of%20Kuwait [accessed 1 Jan 2024].

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https://www.cbd.int/gbo/gbo5/publication/gbo-5-en.pdf [accessed 26 Dec 2023].

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Chapter 4
Impacts of Climate Change and Major Developments on Flow Dynamics in the Upper Senegal River Basin

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Abstract

For several decades, numerous countries have given high priority to the preservation, the use and the sustainable development of water resources in order to provide responses to the deficit of hydrological flow and in response to increasing population demands. Facing these various evolutions, Senegal River basin is going to experience a set of major arrangements on some of its sections (Manantali on Bafing River, Diama in the Valley). The evaluation of the evolution of the flows of rivers interests the scientific community and allows them to understand the characteristics of the modification of flows due to climate change. In this study, the flow trends on both sides of the Manantali Dam in the Upper Senegal River basin were assessed. The assessment was carried out for the period 1970 to 2019 using the Sen slope and the Mann-Kendall Test. The results of the study showed that there was an upward trend in the flow of the Senegal River both annually and for each month upstream (Bafing-Makana station) and downstream (Bakel station) from the Dam. The highest upward trend is noted in October at the upper station with 4.1147 m^3/month and in September at the lower station with 10.9858 m^3/month. On the other hand, the weakest upward trend is observed in May at the upstream station with 0.0712 m^3/month, and in August at the downstream station with 0.6723 m^3/month. In addition, the results of the study also confirmed that the increase in precipitation, despite the construction of hydraulic structures, increased the flow of the River. The findings of the study suggest that the rising trends could cause flooding in the future if appropriate adaptation measures are not taken.

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4.1 Introduction

High concentrations of greenhouse gases cause an increase in global temperature.(2) The increase in temperature plays an adverse role in changing the components of the global hydrological cycle.(3) However, the impacts of climate change on precipitation could be positive or negative depending on geographic location. Precipitation is considered the most vigorous component of the global hydrological cycle, which is reported to have changed in several regions of the global world.(4) Alteration of precipitation characteristics can have serious consequences on society in the form of floods and droughts, which can have a negative impact on the socio-economic status of people.(5) Changes in stream or river flow are often associated with changes in rainfall.(6) River flow trend assessments provide basic water-related information.(7)

Senegal, located in tropical Africa, has also experienced changes in rainfall and temperature over the past fifty years.(8) In view of the succession of extreme climatological (droughts and floods) and hydrological (floods and low water levels) episodes, the studies carried out on the Senegal River Basin have therefore proceeded to analyze the data to characterize climate change in this Basin.

To remedy this decrease in flows during drought years (decades, 1970s, 1980s), ensure better control of water resources, and stimulate development actions, the Organization for the Development of the Senegal River (OMVS) has carried out major developments on the Senegal River, Dams Diama (in 1986) and Manantali (in 1988) in particular. In this context of hydrological deficit (According to Servat,

(2) Jesse Crawford, Kartik Venkataraman and Juliann Booth, "Developing Climate Model Ensembles: A Comparative Case Study", *Journal of Hydrology* 568 (Jan 2019): 160-173, e-article, Science Direct (database), ELSEVIER.

(3) Ahmed Kamal, *et al*., "Climate Change Uncertainties in Seasonal Drought Severity-Area-Frequency Curves: Case of Arid Region of Pakistan", *Journal of Hydrology* 570 (Mar 2019): 473-485, e-article, Science Direct (database), ELSEVIER.

(4) Amogne Asfaw, *et al*., "Variability and Time Series Trend Analysis of Rainfall and Temperature in Northcentral Ethiopia: A Case Study in Woleka Sub-Basin", *Weather and Climate Extremes* 19 (Mar 2018): 29-41, online e-article, Science Direct (database), ELSEVIER, https://www.sciencedirect.com/science/article/pii/S2212094717300932.

(5) Hicham Ezzine, Ahmed Bouziane and Driss Ouazar, "Seasonal Comparisons of Meteorological and Agricultural Drought Indices in Morocco Using Open Short Time-Series Data", *International Journal of Applied Earth Observation and Geoformation* 26 (Feb 2014): 36-48, e-article, Science Direct (database), ELSEVIER.

(6) Ali Rawshan, *et al*., "Long Term Historic Changes in the Flow of Lesser Zab River, Iraq", *Hydrology* 6, no. 22 (2019): 1-12, online e-article, MDBI (database), https://www.mdpi.com/2306-5338/6/1/22.

(7) Sarita Gajbhiye, "Precipitation Trend Analysis of Sindh River Basin, India, from 102-Year Record (1901–2002)", *Atmospheric Science Letters* 17, no. 1 (Jan 2016): 71-77, online e-article, Wiley Online Library (database), Wiley, https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/asl.602#:~:text=Mean%20and%20SD%20of%20the,the%20period%20of%201901%E2%80%932002.

(8) Cheikh Faye, Grippa Manuela and Stephen A. Wood, "Use of the Standardized Precipitation and Evapotranspiration Index (SPEI) from 1950 to 2018 to Determine Drought Trends in the Senegalese Territory", *Climate Change* 5, no. 20 (Dec 2019): 327-341, online e-article, Research Gate (database), https://www.researchgate.net/publication/336221816_Use_of_the_Standardized_Precipitation_and_Evapotranspiration_Index_SPEI_from_1950_to_2018_to_determine_drought_trends_in_the_Senegalese_territory_Citation_Climate_Change.

et al. (1998), this flow deficit of the Senegal River at Bakel was around 50% in 1967), the installation of these structures made it possible to control flows on the Bafing section and to manage floods in the downstream part of the Senegal River Basin (from Bakel).

Over the most recent period, some studies have highlighted the increase in rainfall and runoff in the area since the 2000s, which presages an improvement in the hydrological regime(9) and an increase in flooding. Knowledge of river flow evolution in Senegal is often limited due to data availability and quality. This study examined non-parametric methods that can provide trends and their significance when data quality is uncertain.

4.2 Study Area

The Senegal River, some 1,700 km long, drains a basin of 300,000 km^2, straddling four countries which are, from upstream to downstream, Guinea, Mali, Senegal and Mauritania (Figure 4.1). It goes from 10°20’ to 17° N, and from 7° to 12°20’ W and is made up of several tributaries, the main ones being the Bafing, the Bakoye and the Falémé which have their sources in Guinea and form the upper basin (OMVS/FEM/BFS Project, 2008) (Figure 4.1). The Senegal River thus formed by the junction between the Bafing and the Bakoye, receives the Kolimbiné then the Karokoro on the right and the Falémé on the left, 50 km upstream from Bakel. In the southern part of the basin, the density of the surface hydrographic network testifies to the impermeable nature of the land.(10), (11)

(9) Abdou Ali, Thierry Lebel and Abou Amani, “Signification et usage de l’indice pluviométrique au Sahel”, *Sécheresse* 19, no. 4 (2008): 227-235, e-article, John Libbey Eurotext (database).

(10) Pierre Michel, “Les bassins des fleuves Sénégal et Gambie: Étude géomorphologique”, *Mémoires ORSTOM* 63 (1973): 1-810, online e-article, *Horizon Pleins Textes* (database), https://www.documentation.ird.fr/hor/fdi:06464.

(11) C. Rochette, *Le bassin du fleuve Sénégal, Monographies hydrologiques ORSTOM* 1 (Paris: ORSTOM, 1974), online e-book, http://www.hydrosciences.fr/sierem/Bibliotheque/biblio/Monographies/N%C2%B01-Monographie%20du%20fleuve%20S%C3%A9n%C3%A9gal.pdf.

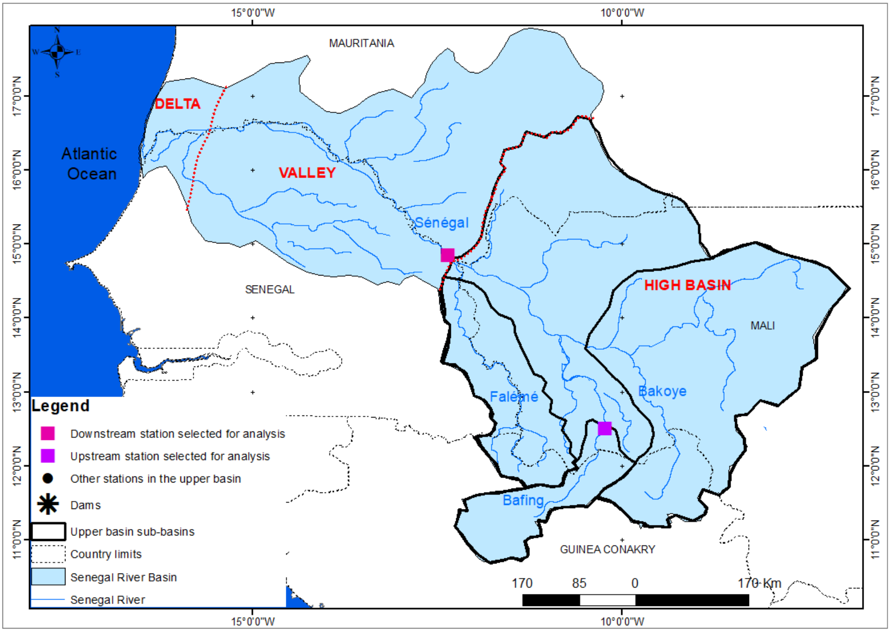

Figure 4.1: Location of the Senegal River watershed and its upper basin.

The basin is generally divided into three entities: the upper basin, the valley and the delta, which differ greatly in their topographical and climatological conditions. The upper basin, our study area, is from the sources of the River (the Fouta Djalon) to the confluence between the Senegal River and the Falémé (downstream of Kayes and upstream of Bakel). It provides almost all of the water inflows (more than 80% of the inflows) from the River to Bakel, as it is relatively humid.(12)

The Senegal River basin has experienced climatic upheaval since the 1970s.(13) To remedy this, a series of developments (Diama and Manantali) were initiated, completely transforming the hydrological dynamics of the Senegal River basin. The Manantali Dam is located on the Bafing River, the main tributary of the Senegal River, 90 km upstream from Bafoulabé (Figure 4.1).(14) Built between 1982

(12) Organisation pour la Mise en Valeur du Fleuve Sénégal (OMVS), *Plan d'action stratégique de gestion des problèmes environnementaux prioritaires du bassin du fleuve Sénégal 2017-2037* (Dakar: OMVS, 2017), https://aquaknow.jrc.ec.europa.eu/sites/default/files/PAS-2016FICHES_MESURES.pdf.

(13) Cheikh Faye, *Évaluation et gestion intégrée des ressources en eau dans un contexte de variabilité hydroclimatique: Cas du bassin versant de la Falémé* (PhD diss., Université Cheikh Anta Diop de Dakar, 2013): 309.

(14) Cheikh Faye, "Impact du changement climatique et du barrage de Manantali sur la dynamique du régime hydrologique du fleuve Sénégal à Bakel (1950-2014)", *Bulletin de la Société Géographique de Liège* 64 (2015): 69-82. online e-article, https://popups.uliege.be/0770-7576/index.php?id=4044&file=1#:~:text=De%20fa%C3%A7on%20g%C3%A9n%C3%A9rale%2C%20de%201950,%C3%A9galement%20une%20cassure%20en%201975.

and 1988, the Manantali Dam consists of a 1,460 m long dam and is 66 m high at the foundation. At the Institut Géographique National (IGN) filling level of 208 meters, its reservoir has a capacity of 11.3 billion m^3 and covers an area of 477 km^2. The Manantali Dam regulates the flow of the Senegal River and makes it possible to irrigate a potential of 255,000 ha of land, and in the long term, should allow the navigability of the River over approximately 800 km from the mouth and the production of energy.(15)

4.3 Data and Methods

4.3.1 Data

The database of the upstream station (Bafing-Makana) and the downstream station (Bakel) retained for the mentioned study. The hydrometric data were made available to us by the Organisation pour la Mise en Valeur du Fleuve Sénégal (OMVS). These data concern the daily flows (1970–2019) from which the annual and seasonal flows are calculated, then the analysis was made.

4.3.2 Methods

a) Frequency Analysis

Distribution analyzes are frequently performed on hydrological studies to understand the nature of the data.(16) Several frequency distribution methods are available in the literature, such as normal, log normal, uniform, generalized extreme value, binomial, gamma, etc. In the current study, the gamma, generalized extreme value and normal distributions, which are widely used in climate studies, were applied to the Dukan Dam datasets. Extreme gamma and generalized values are widely used to adjust skewed data, which is often observed in hydrological data.(17) Also, the normal distribution was used because it has often been found that the river flow follows this distribution. The goodness of fit for the tests was assessed using the Kolmogorov-Smirnov (KS) test. The KS test is found to be more powerful than the Anderson-Darling test and Chi-Square.(18) Therefore, the test was applied to the discharge of each month, the module, the annual maximum discharge, the annual minimum discharge, and the discharge of high and low water periods with a confidence level of 95%.

(15) Yves Ficatier and Madiodio Niasse, "Volet social et environnemental du barrage de Manantali", *Série Évaluation et Capitalisation* 15 (2008): 1-69, online e-article, https://www.oecd.org/countries/madagascar/42096522.pdf.

(16) Muhammad Noor, *et al*., "Uncertainty in Rainfall Intensity Duration Frequency Curves of Peninsular Malaysia under Changing Climate Scenarios", *Water* 10, no. 12 (2018): 1750, online e-article, MDPI (database), https://www.mdpi.com/2073-4441/10/12/1750.

(17) *Ibid*.

(18) *Ibid*.

b) Estimating the Magnitude of Change

In this study, Sen's slope method(19) was applied to calculate the intensity of change in river flow. The method is non-parametric and calculates the slope with an equal pair of data. The method is well-known and widely used for trend calculation.(20)

c) Mann-Kendall Trend Tests

The Mann-Kendall (MK) test is frequently used to assess trends and is a non-parametric test.(21) The test is also approved by the World Meteorological Organization (WMO) for assessments of hydrometeorological trends.

4.4 Results and Discussion

4.4.1 Frequency Analysis

The results obtained are shown in (Table 4.1). Values in **bold** in the Table indicate that the test hypothesis is rejected at the 95% confidence level, while values in *italics* indicate the best fit. At the upstream station (Bafing-Makana), it was found that all data followed the gamma distributions, while the null hypothesis was rejected in some months (June to October), on the modulus, on the maximum flow and on the high and low water flow for the normal and GEV.

Table 4.1: Kolmogorov-Smirnov test statistics obtained during the adjustment distribution of the Senegal River flow at the upstream (Bafing-Makana) and downstream (Bakel) Stations of the Dam

Parameters	Upstream Station			Downstream Station		
	Gamma	GEV	Normal	Gamma	GEV	Normal
May	*0.4287*	*0.3621*	0.2297	*0.4779*	0.2466	0.1941
June	*0.4183*	**0.0694**	**0.1631**	*0.4476*	**0.1100**	**0.1101**
July	*0.4638*	**0.0737**	**0.1159**	*0.4717*	**0.0695**	**0.1270**
August	*0.3907*	**0.1107**	**0.1143**	*0.5477*	**0.0869**	**0.1265**
September	*0.4952*	**0.1125**	**0.1478**	*0.5078*	**0.1131**	**0.1052**
October	*0.4166*	**0.0831**	**0.0933**	*0.5578*	0.2996	**0.1499**
November	*0.5064*	*0.5165*	0.2022	*0.5144*	*0.7551*	0.2028
December	*0.3534*	0.2209	0.2052	*0.4323*	*0.4774*	0.2090

(19) Pranab Kumar Sen, "Estimates of the Regression Coefficient Based on Kendall's Tau", *Journal of American Statistical Association* 63, no. 324 (1968): 1379-1389, online e-article, Taylor and Francis Online (database), https://www.tandfonline.com/doi/abs/10.1080/01621459.1968.10480934.

(20) Sarita Gajbhiye, "Precipitation Trend Analysis of Sindh River Basin": 71-77.

(21) Henry B. Mann, "Nonparametric Tests against Trend", *Econometrica* 13, no. 3 (1945): 245-259, e-article, JSTOR (database).

Parameters	Upstream Station			Downstream Station		
	Gamma	GEV	Normal	Gamma	GEV	Normal
January	0.3217	*0.5292*	0.2279	*0.5338*	**0.1491**	**0.1676**
February	0.2990	*0.5918*	0.2444	*0.4414*	**0.1144**	**0.1206**
March	0.2883	*0.4898*	0.2055	*0.4231*	**0.1654**	**0.1631**
April	0.2907	*0.5170*	**0.1645**	*0.4688*	0.2225	0.2013
Module	0.3158	**0.0997**	**0.1087**	*0.4808*	**0.0855**	**0.1256**
Maximum Flow	*0.4665*	**0.0618**	**0.0651**	*0.4897*	**0.0738**	**0.0758**
Minimum Flow	*0.3711*	*0.6479*	0.2338	*0.4490*	*0.3125*	0.2015
High Water	*0.3884*	**0.1000**	**0.0938**	*0.5254*	**0.0650**	**0.1142**
Low Water	*0.3269*	**0.0695**	**0.1546**	*0.4474*	**0.1174**	**0.1099**

Similarly, for the downstream station (Bakel), all data were found to follow the gamma distribution. In the generalized distribution of extreme values, it was found that over the months of March to September and January to March, the modulus, the annual maximum flow, and the flow of the high and low water periods indicated that the null hypothesis is rejected. Similarly, in the normal distribution, the null hypothesis is rejected on the same variables (months of March to September and months of January to March, module, maximum annual flow, and flow of high water and low water periods) in addition to the month of October.

4.4.2 Seasonal Flow Distribution

Figure 4.2 shows the seasonal distribution of the monthly flow over the period 1970–1987 (the period before the Dam) and the period 1988–2019 (the period after the Dam) at the Bafing-Makana Station located on the upstream part of the Manantali Dam. Over the two periods, we note a similar evolution despite slightly higher monthly flows over the period 1988–2019. The peaks are noted in September (with 740 m^3/s 1970–1987, and 867 m^3/s 1988–2019) and the lowest flows in April in 1970–1987 (with 3.8 m^3/s) and May in 1988–2019 (with 5.9 m^3/s). Discharges in the months of the high water period (July, August, September and October) showed the highest discharges in both periods. During the low water period (the rest of the year), the flows remained the lowest.

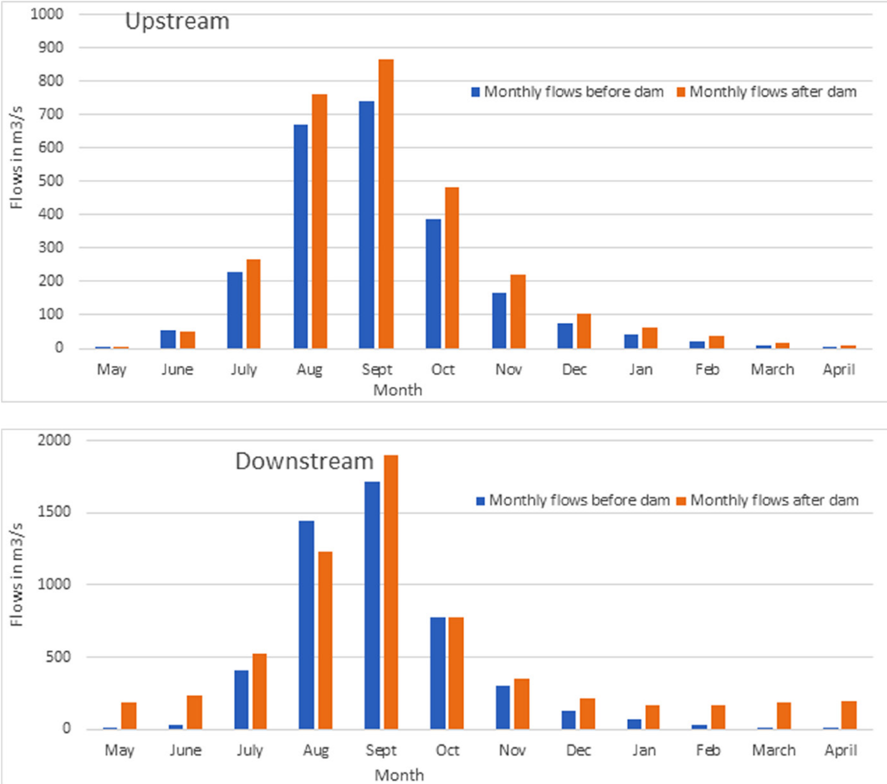

Figure 4.2: Seasonal distribution of flow recorded upstream (a) and downstream (b) of Manantali Dam.

The seasonal distribution of the monthly flow over the period 1970–1987 (period before Dam) and the period 1988–2019 (period after Dam) recorded at the Bakel station located in the downstream part of the Manantali Dam, is given in Figure 4.3. In the downstream part of the Dam, the evolution of the flow shows a clear opposition between the period 1970–1987 (whose evolution is quite similar to that noted in Bafing-Makana over the two periods) and 1988–2019 which witnessed its flows in periods of low water strongly increased (its minimum flow is more than 90 times greater than that of 1970–1987). This increase is explained by the policy of supporting the low water levels of the Manantali Dam. However, over both periods, the peaks are noted in September (with 1714 m^3/s in 1970–1987, and 1902 m^3/s in 1988–2019) and the lowest flows in May 1970–1987 (with 2.07 m^3/s) and in 1988–2019 (with 188 m^3/s). Contrary to the pre-Dam period, over the post-Dam period, it can be noted that the flow began to increase from January, after a decrease from

September to January, which is in contradiction with the flow before the Dam, where it started to decrease from September to April. The increases in flow are due to the excess water in the reservoir and the maintenance of a minimum flow in the River. It also emerges from Figures 4.2 and 4.3 that the flow was very low from December to May upstream, while it rises over this period in the downstream part.

4.4.3 Monthly and Annual Flow Trends

Table 4.2 presents the Z-statistic (Kendall's Tau), the significance at the 90% to 95% confidence levels, and Sen's Slope of the trend for each variable. The results show significant increases in trends on both sides of the Dam (of all the variables, only June showed a decreasing trend in flow at the Bafing-Makana station). Upstream, the months of October through April showed significant trends at the 99% confidence level. The May trends were significant at the 95% confidence level, while the July trends were significant at the 90% confidence level. It is important to mention here that the modulus, minimum flow and low water flow also had significant positive trends at the 99% confidence level. The highest significant trend with 4.11 $m^3/s/year$ was observed for the month of October, followed by August with 2.87 $m^3/s/year$. On the other hand, the modulus trend showed a variation of 1.82 $m^3/s/year$ with a confidence level of 99%. It can also be noted that only one monthly flow (June) showed a slight downward trend. Increasing trends have also been observed in river flow in other parts of the world.[22]

(22) G. E. Soro, *et al*., "Caractérisation des séquences de sécheresse météorologique à diverses échelles de temps en climat de type soudanais: Cas de l'extrême Nord-ouest de la Côte d'Ivoire", *Larhyss Journal* 18 (2014): 107-124, online e-article, http://archives.univ-biskra.dz/bitstream/123456789/2892/1/8.Soro_et_al.pdf.

Table 4.2: Trends in monthly and average annual river flows obtained using Sen's slope and Mann-Kendall trend test located upstream and downstream of Manantali Dam

Parameters	Upstream Station (Bafing Makana)			Downstream Station (Bakel)		
	Kendall's Tau	Significance	Sen's Slope	Kendall's Tau	Significance	Sen's Slope
May	0.2135	**	0.0712	0.6344	***	6.9206
June	-0.0034		-0.0077	0.6361	***	7.7636
July	0.1650	*	1.8607	0.3844	***	5.6139
August	0.1480		2.8723	0.0119		0.6723
September	0.1361		2.3319	0.1378		10.9858
October	0.3180	***	4.1147	0.0493		1.5702
November	0.4286	***	2.6147	0.1259		1.5357
December	0.3861	***	1.1942	0.2126	**	1.8892
January	0.4082	***	0.7428	0.4337	***	3.2915
February	0.4541	***	0.5293	0.6020	***	4.9282
March	0.4507	***	0.3203	0.6003	***	5.9834
April	0.4065	***	0.1739	0.6344	***	6.7668
Module	0.3452	***	1.821	0.2619	***	4.531
Maximum Flow	0.0255		2.1833	0.0952		10.8645
Minimum Flow	0.5352	***	0.0709	0.6785	***	3.9356
High Water	0.2466	**	2.9862	0.0884		4.3142
Low Water	0.3384	***	0.8891	0.5748	***	5.3217

*Significant at 90%, **Significant at 95%, and ***Significant at 99%.

It can be noted that the largest monthly increase (10.98 m^3/s) was recorded in September, followed by May (6.92 m^3/s) and April (6.76 m^3/s). It is also important to note that the changes were significant over the months of May to July, and January to April at the 99% confidence level. A significant change was observed in December at the 95% confidence level. Like the upstream station, the modulus, minimum flow and low water flow also showed significant positive trends at the 99% confidence level. The significant upward trend in the low water months (March, April and May) is explained by the low water support policy of the Dam.

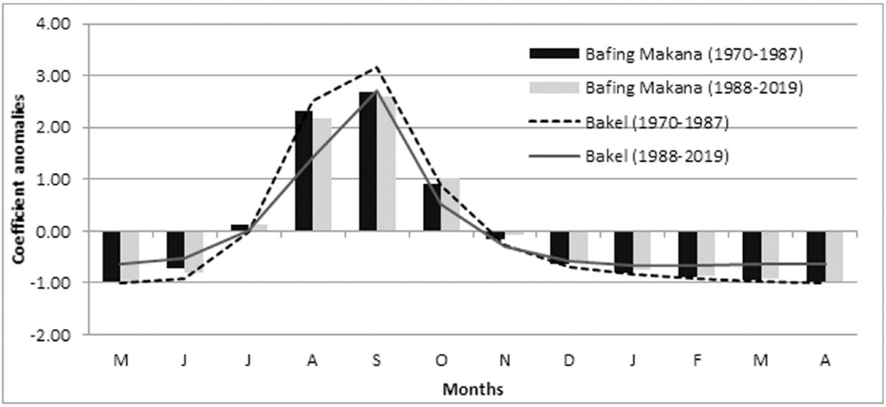

Figure 4.3: Comparative evolution of monthly flow coefficient anomalies between 1970–1987 and 1988–2019 at Bakel and Bafing-Makana stations.

The Manantali Dam, which was launched in 1988, shows a difference in the number of high-water months (i.e. months with CMD >1). Over the period 1970–1987, the number of high-water months is 3 months, while over the period 1988–2019, it is 4 months (Figure 4.3). This difference is explained by the effects of the Dam over the 1988–2019 period; while over the 1970–1987 period, the river had a natural flow. Thus, the impoundment of the Manantali Dam changes the basin regime at the Bakel Station from a pure tropical river regime (before Dam) to a transitional tropical river regime (after the Dam). In addition, the high-water discharge has increased from 506 m^3/s (1970–1987) to 595 m^3/s (1988–2019) in the upstream basin (an increase of 17.6%); and from 1085 m^3/s (1970–1987) to 1109 m^3/s (1988–2019) in the downstream part of the basin (a small increase of 2.21%). As for the low-water flow, it increased from 68.1 m^3/s (in 1970–1987) to 85.8 m^3/s (in 1988–2019) in the upstream part of the basin (a slight increase of 25.9%) and from 111 m^3/s (in 1970–1987) to 248 m^3/s (in 1988–2019) in the downstream basin (a significant increase of 124%). The Dam causes an increase in monthly flows during the low-water period and a decrease in monthly flows during the high-water period.

Despite the presence of the Manantali Dam and its policy of flood reduction which reduces the maximum flow,[23] the increase in precipitation has led to an increase in the flows flowing into the basin. Thus, the maximum flow increased from 1327 m^3/s (1970–1987) to 1495 m^3/s (1988–2019) in the upstream part of the basin (an increase of 12.6%) and from 2744 m^3/s (1970–1987) to 2790 m^3/s (1988–2019) in the downstream part of the basin (a slight increase of 1.69%). Overall, the increase in maximum flow has been relatively greater in recent years on both sides of the Dam.

4.4.4 Trends in Annual Minimum Flow

Trends in the minimum flow on both sides of the Dam were also evaluated based on the minimum values recorded each year. The results obtained are presented in Figure 4.4 which clearly shows that there was a strong increase in the minimum flow on both sides of the Dam. However, the increase was relatively greater on the downstream side of the Dam (the increase being 3.9356 m^3/s) than on the upstream side (the increase being only 0.0709 m^3/s). Nevertheless, it is statistically significant on both sides of the Dam at the 99% confidence level. If the upward trend in the minimum flow on the upstream part of the Dam is strictly linked to the return of rainfall, that noted on the downstream part of the Dam and which is very significant is much more linked to the policy of supporting low water levels by the Dam,[24] although increased rainfall contributed.

(23) Faye, “Impact du changement climatique”: 69-82.
(24) *Ibid*.

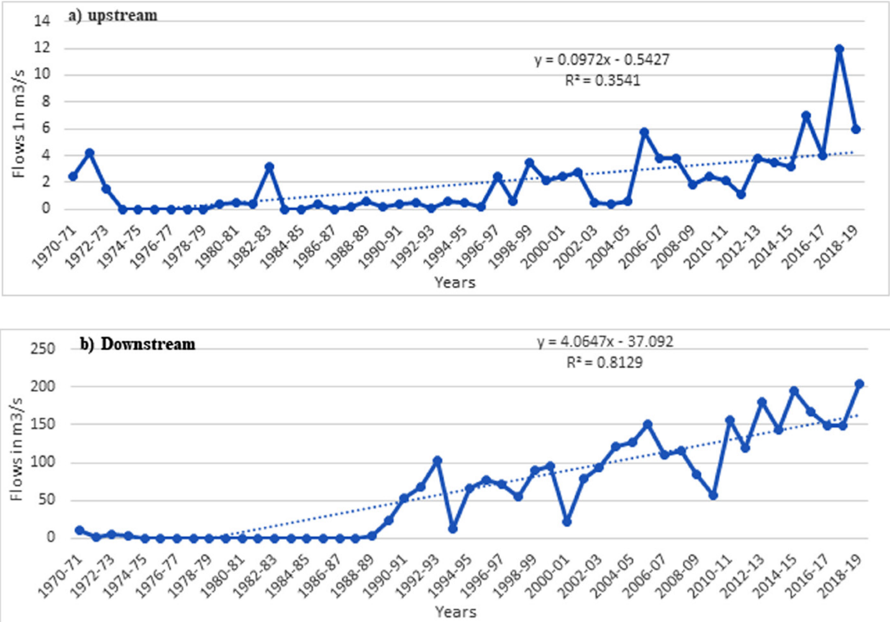

Figure 4.4: Trends in the annual minimum flow of the Senegal River (a) upstream and (b) downstream of the Manantali Dam.

During the 2000s in Senegal, an increase in rainfall was noted, presaging the improvement of rainfall patterns in the country, compared to the drought period, although the persistence and sustainability of the increase remains to be proven. Over the period 2000–2019, significant wet sequences were detected in Senegal, which soon impacted the flow in the basin. Beyond that, the rolling action of the floods and the support of the low flows of the Manantali Dam also impact the flow in the basin. Thus, the minimum flow increased from 0.73 m^3/s (1970–1987) to 2.56 m^3/s (1988–2019) in the upstream part of the basin (an increase of 248%) and from 1.16 m^3/s (1970–1987) to 101 m^3/s (1988–2019) in the downstream part of the basin (a significant increase of 8658%).

4.5 Conclusion

The results of the study showed that the generalized trend at the extremes was more consistent with the flow data from the Manantali Dam. The results of the trend analysis showed that the river flow increased almost every month on both sides of the Dam. October recorded the highest rate of change upstream, while September recorded the highest rate of change downstream of the Dam. May and August showed the smallest changes upstream and downstream the Dam respectively. Significant changes were noticed in the months of May, June, January, February, and March. Similarly, the changes in the annual river discharge were also found to be significant. Significant positive changes were also observed first in the maximum and minimum flows, then in the high and low water flows on both sides of the Dam. The maximum flow was found to have increased relatively significantly on the upstream side of the Dam, indicating increased precipitation. In addition, the construction of hydraulic structures may be a major cause of increased flow during low water periods. The results of this study are expected to contribute to the planning and management of agriculture and water resources in the Senegal River basin.

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Chapter 5
Climate Change Priorities in Arab Countries

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5.1 Introduction

Frequent Intergovernmental Panel on Climate Change (IPCC) assessment reports have been sounding alarm that climate change is one of the most profound global challenges in the 21st century.[2], [3], [4] This is due to the fact that it represents not just an environmental challenge but also a multidimensional one, affecting the essence of economic system as well as socio-cultural systems. Vulnerability of human and natural systems and thus the consequences of climate change would depend upon risk magnitude and exposure, sensitivity of these systems and their ability to adapt to such risks. This means that vulnerability of such systems and their adaptive capacities would differ with geographic location, time and socioeconomic and environmental conditions.

Arab countries are expected to face more adverse impacts due to not only their location, present socioeconomic conditions but also to lack of resources and limited capabilities in most of these countries. Nevertheless, very little efforts to quantify accurately future impacts of climate change and vulnerabilities at different levels have been actually undertaken. Moreover, it could be suggested that such efforts are mostly scattered and no inter-linkages between the research institutions or the projects are present.

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(2) Rajendra K. Pachauri, *et al*., eds., *Climate Change 2014: Synthesis Report: Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva: The Intergovernmental Panel on Climate Change (IPCC), 2014), https://research-repository.uwa.edu.au/en/publications/climate-change-2014-synthesis-report-contribution-of-working-group.

(3) The Intergovernmental Panel on Climate Change (IPCC), *Climate 2007: Synthesis Report* (Geneva: IPCC, 2008), https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf.

(4) J. T. Houghton, *et al*., eds., *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University press, 2001), https://www.ipcc.ch/site/assets/uploads/2018/03/WGI_TAR_full_report.pdf.

In order to be able to identify priorities for climate change action, there is a need to assess vulnerability to climate change. This chapter intends to examine climate change priorities in Arab countries, beginning with a review of prevailing economic, socio-cultural and environmental conditions in Arab countries. This is followed by identifying and discussing the main issues that may arise from climate change and the sectors that would be affected most by such issues. The chapter is then concluded with several aspects about the way ahead in this respect.

5.2 Arab Countries: A Situation Analysis

Arab countries, which have a total area of over 5 million square miles, have been experiencing rapid increase during the past three decades from 164 million to 436 million in 1980 and 2020, respectively, with an annual increase rate of 4%.[(5)]

The diverse Arab region can be characterized as predominantly energy rich, water scarce, and food deficient.[(6)] The region, though has a history of dealing with an unforgiving climate including low precipitation, frequent floods, droughts and extreme temperature with societal changes such as rapid population and urban growth, and widespread poverty, is considered to be among the world's most vulnerable regions to climate change.[(7)]

The Arab region has experienced rapid population growth, from 122 million in 1970 to over 407 million in 2016, and is projected to reach 646 million by 2050 (Figure 5.1). Additionally, urban population, which has more than quadrupled from 1970 to 2010, is expected to more than double again by 2050 and reach over 439 million people.[(8)]

Despite what has been said before, Arab countries are marked by remarkable diversity, with wealth disparities among countries in the region, for instance, are among the highest in the world.[(9)] While the annual per capita Gross Domestic Product (GDP) of Qatar is just under US$ 130,000, six countries in the region are

(5) World Bank Group, "Population, Total World Bank", *World Bank*, https://data.worldbank.org/indicator/SP.POP.TOTL?locations=1A.

(6) Najib Saad, ed., *Arab Environment in 10 Years* (Beirut: Arab Forum for Environment and Development (AFED), 2017), https://www.academia.edu/38679762/Arab_Environment_in_10_Years.

(7) *Ibid.*

(8) United Nations Human Settlements Programme (UN-Habitat), *The State of Arab Cities 2012: Challenges of Urban Transition*, 2nd ed. (Nairobi: UN-Habitat, 2012), https://unhabitat.org/the-state-of-arab-cities-2012-challenges-of-urban-transition.

(9) Barry Mirkin, *Population Levels, Trends and Policies in the Arab Region: Challenges and Opportunities*, Research Paper Series (New York, NY: United Nations Development Programme (UNDP), 2010), https://www.researchgate.net/publication/238729642_Population_Levels_Trends_and_Policies_in_the_Arab_Region_Challenges_and_Opportunities.

among Least Developed Countries (LDCs) with predominantly rural populations and a GDP as low as US$ 600 (Somalia).[10] Adult literacy rates range between 56 percent in Morocco to as much as 95 percent in Qatar. While women's labor participation rates range from 13.9 percent (Iraq) to 73.7 percent (Comoros). The Human Development Index (HDI), which summarizes several indicators of average achievement in key dimensions of human development runs between 0.4 (Sudan) to 0.85 (United Arab Emirates).[11]

Largely located in the arid latitudes, the region has the world's lowest freshwater resource endowment. All but four Arab countries (the Arab Republic of Egypt, Iraq, Saudi Arabia, and Sudan) suffer from chronic water scarcity and fall below the water poverty line of 1,000 cubic meters (m^3) per capita per year.[12] Rural populations are heavily dependent on climate sensitive subsistence farming and pastoralism and are therefore vulnerable to increasing rainfall variability caused by climate change. An arid climate and scarce water resources make countries in the region heavily dependent on food imports to feed their populations. Undernourishment is a challenge in some of the region's poorest countries, where non-farm rural households living in remote areas are the most affected.

(10) Dorte Verner, *Adaptation to a Changing Climate in the Arab Countries: A Case for Adaptation Governance and Leadership in Building Climate Resilience*, MENA Development Report (Washington, DC: World Bank Group, 2012).

(11) Human Development Index (HDI), *Human Development Reports (UNDP)*, http://hdr.undp.org/en/content/human-development-index-hdi.

(12) Balgis Osman-Elasha, *Mapping of Climate Change Threats and Human Development Impacts in the Arab Region*, Research Paper Series (New York, NY: United Nations Development Programme (UNDP), 2010), https://arab-hdr.org/wp-content/uploads/2020/12/paper02-en.pdf.

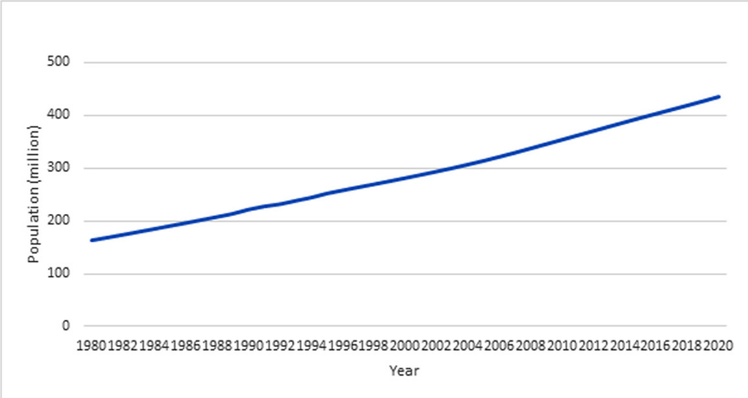


Figure 5.1: Population of Arab Countries (1980–2020).
Source: World Bank.(13)

The value of the agricultural contribution to the GDP has declined in most Arab countries in the past two decades. Overall, in the region, it fell from 8.65% GDP in 2000 to 5.59% in 2020.(14)

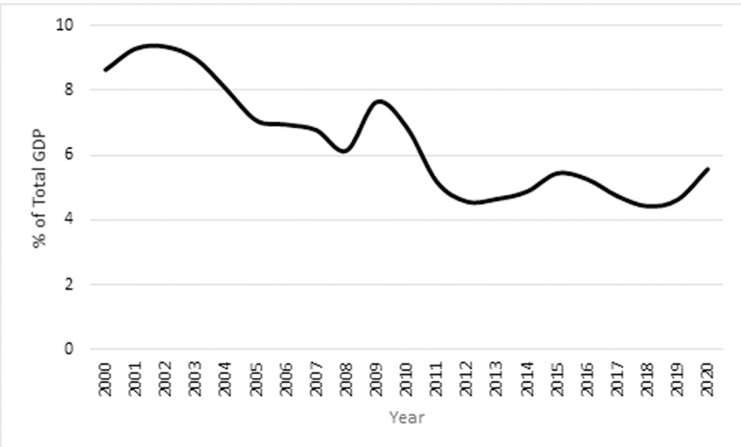


Figure 5.2: The decrease was most dramatic in Jordan, Sudan, Syria, Tunisia, and Yemen.(15)

(13) The World Bank, "Agriculture, Forestry, and Fishing, Value Added (% of GDP)", *The World Bank*, https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?end=2020&locations=1A&start=2000.

(14) *Ibid*.

(15) United Nations and League of Arab States, *The Arab Millennium Development Goals Report: Facing Challenges and Looking Beyond 2015*, E/ESCWA/EDGD/2013/1 (Beirut: United Nations; Cairo: League of Arab States (ESCWA), 2015), https://www.unescwa.org/publications/arab-millennium-development-goals-report-facing-challenges-and-looking-beyond-2015.

In terms of food security most Arab countries are food importers, which means that a large proportion of their population are vulnerable to food insecurity. Food demand has long exceeded domestic production and is expected to continue to do so in the future. Such a situation may exacerbate the overall vulnerability. In this context, Arab countries supposedly have the highest food-deficit, where the gap in the food production and consumption increased steadily by about 7.3% annually over the period 2005–2014.(16) Due to such food insecurity in the Arab region, an estimated US$ one billion is needed to provide immediate relief to those who are food insecure, a figure likely to grow in the future.(17)

It is worth mentioning that, when considering the above stated trends, the Arab region is very heterogeneous in terms of economic and social conditions. Based on socioeconomic and climatic conditions, Arab countries can be classified into four zones namely the North-West Africa and Mediterranean coast, the Desert regions of North Africa, the Levant and the Arabian Peninsula (Figure 5.3).

It was suggested that current climate in the Arab countries is around 1–1.5˚C warmer than pre-industrial times, and there is high confidence of further warming in the future (Figure 5.4), particularly at the hottest times of year.(18)

(16) Saad, *Arab Environment in 10 Years*.
(17) *Ibid*.
(18) Katy Richardson, *et al*., *Climate Risk Report for the Middle East and North Africa (MENA) Region* (Devon, UK: Met Office, 2021), https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/services/government/mena-climate-risk-report-final.pdf.

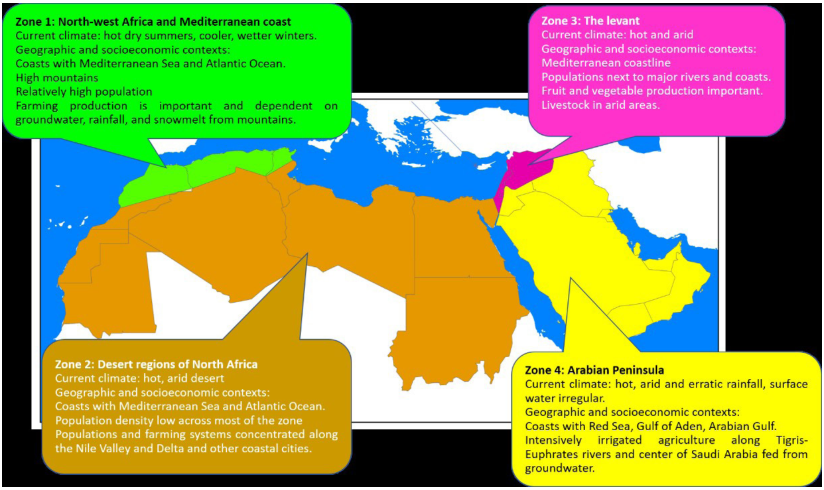


Figure 5.3: Groups of Arab countries.
Source: Met Office Hadley Centre.[19]

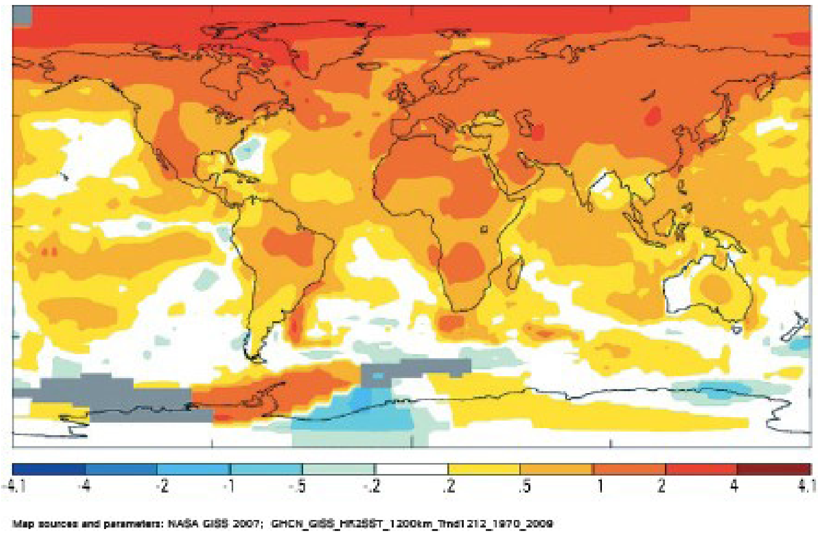


Figure 5.4: Change in temperature (1970–2009).
Source: Met Office Hadley Centre.[20]

(19) *Ibid*.
(20) *Ibid*.

5.3 Profiling Projected Climate Change Parameters

It is worth arguing that understanding how climate risks converge and interact with broader challenges of development and crisis prevention requires first identifying and profiling these risks. In this respect, the most prominent aspects of expected climate change include changes in temperature, precipitation in addition to rising sea levels, and changing patterns of extreme weather events, each of which is very briefly discussed in the remaining part of this section.

5.3.1 Temperature

According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), mean annual temperatures in East Africa and the Maghreb States are likely to exceed 2° Celsius (°C) with maximum projected increases up to 6°C, based on the (representative concentration pathways RCP 2.6 and RCP 8.5 emissions scenarios respectively by the year 2100.(21) Downscaled regional climate modeling for the Arab region shows that, for the period 2011–2041, both models predict similar increases in temperature of about 0–2°C.(22)

5.3.2 Precipitation

Overall, precipitation projections present greater variability than temperature projections.(23) A reduction in precipitation, up to 40 percent, is likely to be experienced over North Africa by the end of the 21st century. Additionally, erratic and insufficient rainfall is being compounded by an increase in extreme temperatures.(24)

5.3.3 Sea Level Rise

By the end of the century, climate change is likely to cause the global mean sea level to rise by 26 cm to 82 cm.(25) Combined with an increase in frequency of storm surges and saltwater intrusion into rivers and aquifers it is likely to affect water quality and agricultural productivity in the low-lying coastal regions. Projections show that Egypt, Libya, Morocco, and Tunisia have been identified as the most exposed African countries in terms of total population that will be affected by sea level rise. For instance, the Nile Delta is threatened by saltwater intrusion and soil salinization. Between 23% and 49% of the total area of coastal governorates of the

(21) Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2014: Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Christopher B. Field, *et al*. (Cambridge: Cambridge University Press, 2014).

(22) Richardson, *Climate Risk Report*.

(23) United Nations (UN), *Arab Sustainable Development Report, 2015* (Beirut: UN, 2016) https://sdgs.un.org/publications/arab-sustainable-development-report-2015-18026.

(24) IPCC, *Climate Change 2014: Impacts*.

(25) Pachauri, *Climate Change 2014: Synthesis Report*.

Nile Delta will be susceptible to inundation according to the AR5.[26] Assuming no protection or adaptation to the SLR in Egypt, annual damages have been projected to be in the range of US$ 5 billion by 2100 for a 1.26–meter SLR.[27]

5.3.4 Extreme Weather Events

Natural calamities are projected to worsen, and temperatures continue to reach record highs, with 2017 extreme heat waves for instance recorded across the Arab region and the hottest temperature in the world recorded in Kuwait. Additionally, droughts, storms, and flash floods are expected to increase in frequency and magnitude, leading to significant consequences to human life, livelihood, and economic assets, particularly urban infrastructure.[28]

5.4 Climate Change Associated Challenges

Generally, a snapshot of climate change in Arab countries reveals that:

- Higher temperatures and more frequent and intense heat waves threaten lives, crops, and terrestrial and marine ecosystems such as coral reefs and fisheries.
- Less overall but more intense rainfall causes both more droughts and more frequent flash flooding, with the loss of winter snow masses inducing summer droughts.
- Increased extreme weather events may also lead to losses in human life, livelihoods, and incomes.
- Sea-level rise threatens coastal areas, particularly river deltas, coastal cities, wetlands, and island nations with flooding, storm surges and saltwater intrusion.
- Changing rainfall patterns and temperatures may expose new areas to vector- and waterborne diseases, such as dengue and malaria, affecting people's health and productivity.[29]

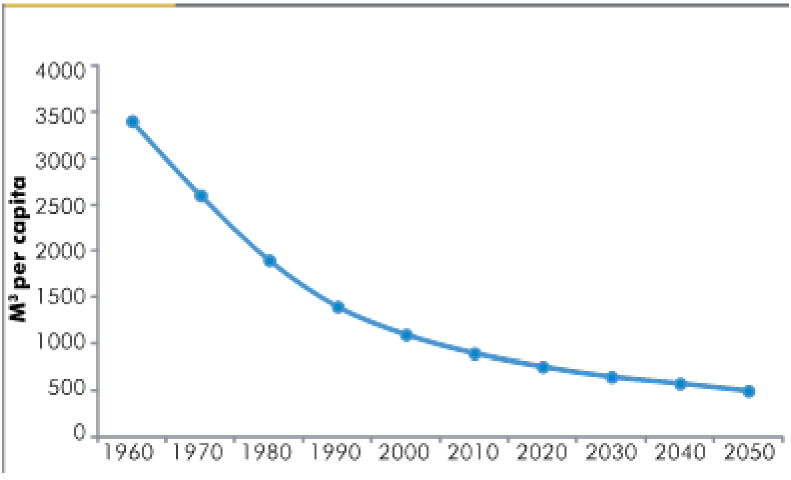
With such a wide range of climate change impacts on Arab countries, priority areas can be summarized as water security, food security, health, cities, and infrastructure and conflict.

(26) *Ibid*.
(27) The World Bank Group. "Turn Down the Heat: Confronting the New Climate Normal", *Open Knowledge Repository Beta*, https://openknowledge.worldbank.org/entities/publication/98508814-21c5-53e6-b36c-912a4ecf9da7.
(28) United Nations, *Arab Sustainable Development Report,* 2015.
(29) Dorte Verner, *et al*., *Economics of Climate Change in the Arab World: Case Studies from the Syrian Arab Republic, Tunisia, and the Republic of Yemen* (Washington, DC: World Bank Group, 2013).

5.4.1 Water Security

Currently, the Arab region is considered to be by far one of the lowest regions in the world in terms of renewable water resources in the world. In this respect, while the world average annual per capita freshwater availability is 7,525 m^3/capita/year, the annual per capita in Arab region dropped by about 20%, from about 990 m^3 to 800 m^3 during the period 2005–2015, which is below the UN water scarcity threshold (1,000 m^3) (Figure 5.5).[30] Moreover, average annual available water per capita in the Arab countries is expected to decrease further to 460 m^3 by 2023, placing most Arab countries in the category of "severe water stress".

Global warming in addition to increasing variability of rainfall can lead to increased heat stress, which in turn will increase human, animal and plant demand for water. Also, rising temperatures will have significant impacts on springtime snowmelt which feeds many key rivers, particularly in Levant zone, leading to decrease in freshwater availability. It is estimated, in this context, that water demand in the Arab region is projected to increase by 60% by 2045, while climate change is expected to reduce water runoff by 10% by 2050.[31]



المصدر: متوسط نصيب الفرد من المياه في الدول العربية (١٩٥٠–٢٠٢٠)
المصدر: AFED.[32]

Figure 5.5: Water resource per capita in Arab countries (1950–2050).
Source: AFED.[33]

(30) Saad, *Arab Environment in 10 Years*.
(31) *Ibid*.
(32) Abdul-Karim Sadik, Mahmoud El-Solh and Najib Saad, *Arab Environment: Food Security Challenges and Prospects* (Beirut: Arab Forum for Environment and Development (AFED), 2014), http://www.afedonline.org/uploads/afed_reports/2014.pdf.
(33) *Ibid*.

It is worth mentioning that climate change impacts on water security will vary across the region. The most vulnerable countries are said to be those that depend on rainfall or rivers.(34) Nonetheless, the Arabian Peninsula, which lacks freshwater resources and thus depends heavily on desalination, will also be impacted by increasing salinity levels associated with climate change; desalination activities may become technologically problematic with reverse osmosis.(35)

5.4.2 Food Security

Climate change and associated limited water supply, rising temperature and degraded arable land are expected to have significant impacts on crop productivity. Rising temperature overall seasons, increased evapotranspiration and in some locations more variable rainfall, will contribute to greater draught risk and harvest failure. Also, shorter growing seasons in many areas are expected, particularly in already vulnerable agricultural systems.

Therefore, food imports will play a crucial role in food supplying for increasing population, which will leave food systems vulnerable to volatility of global food markets. This is of particular concern as increasing reliance on food imports expose Arab countries to price and supply volatility as climate change may affect global food exporting countries.

5.4.3 Health

Human health is likely to be impacted directly and indirectly by climate change, through heat-stress and vector-borne, and vector and water-borne diseases.(36) Directly, rising temperatures will increase heat stress that are projected to become more intense, frequent, and prolonged. This may mean that outdoor labor productivity is likely to be reduced in summer months. For example, it was suggested that climate change could push temperatures in some regions of the Arabian Gulf beyond a threshold of human adaptability.(37) Also, the incidence of infectious diseases as malaria will become more prevalent and enter new territories as higher temperatures reduce the incubation period, spread the range of malaria-bearing mosquitoes, and increase their abundance. Indirectly, climate change impacts on water availability, and food security could further impact human health.(38)

(34) United Nations. *Arab Sustainable Development Report,* 2015.

(35) Jane Glavan, *Technical Report: Regional Desalination and Climate Change* (Abu Dhabi: Abu Dhabi Global Environmental Data Initiative (AGEDI), 2016), https://www.researchgate.net/publication/311143429_Technical_Report_Regional_Desalination_and_Climate_Change.

(36) Elasha, *Mapping of Climate Change*.

(37) Jeremy S. Pal, and Elfatih A. B. Eltahir, "Future Temperature in Southwest Asia Projected to Exceed a Threshold for Human Adaptability", *Nature Climate Change* 6, no. 2 (2015): 197-200, e-article, ResearchGate (database).

(38) Elasha, *Mapping of Climate Change*.

5.4.4 Cities and Infrastructure

Economic opportunities will continue to attract new arrivals to the region's urban areas. As urban areas grow, often in an informal way, demand for water will increase and put more pressure on infrastructure in urban areas, such as potable water and sanitation services. Not only that, but extreme heat events also place significant strain on power generation and transmission, roads, and other critical infrastructure, with health and economic consequences.

5.4.5 Conflict

It was noted that while Arab countries hold 5% of the world population, they host about 37% of the world's displaced persons, including refugees, migrants, and internally displaced persons. Climate change may, particularly in fragile states, to more conflict creating new forms of social vulnerability, and because climate change may impact directly and indirectly various sectors, resources and aspects of livelihood, it would be very difficult to predict its consequences on conflict in the region. This is especially true when considering the direct impact of climate change on decreasing water and food security is feeding armed conflict.

5.5 The Way Ahead

Concerns over climate change should inform all areas of public policy, starting with agricultural and broader development strategies. It is worth arguing that dealing with climate change impacts is not only about developing adaptation strategies. Rather, climate actions should be integrated into development plans and strategies, which need to be wherever possible climate proofing.

It can be argued that Arab countries are still way behind in terms of having the prerequisites for proper tackling of climate change impacts. To improve the resilience of Arab countries to expected climate change impacts, there is a need to tackle climate change impacts through:

- Providing material, technical and institutional support to the most vulnerable sectors.
- Mobilizing private financing by developing a supportive policy for private sector that takes into account the potential impacts of climate change.
- Taking all necessary measures to cope with these impacts, including early warning systems, and the provision of insurance tools that can enhance the resilience and resilience capabilities of most vulnerable sectors.

- Investing in research, in a way that enhances the capabilities of researchers, as well as producing knowledge and the possibilities of benefiting from it in Rwanda in order to adapt to climate changes.
- Increasing opportunities for cooperation between the various research bodies in Arab countries in the areas of transfer of expertise and knowledge exchange.
- Restructuring the economy to integrate more resilient activities.
- Dealing with the problems that may exacerbate the effects of climate change on the most vulnerable sectors.

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