# Protecting human health against climate change in Africa

ISBN: 979-8-9859206-1-1

This report can be found at
https://nasaconline.org

## The Network of African Science Academies (NASAC)

NASAC was established on 13th December 2001 in Nairobi, Kenya, under the auspices of the Inter Academy Panel, currently known as the Inter-Academy Partnership (IAP). NASAC is a independent consortium of 28 science academies in Africa. Through its membership, NASAC facilitates the discussion of scientific aspects of challenges of common concern, make statements on major issues and provide mutual support to the academies. Drawing from this, NASAC specifically aims to provide credible science advice to governments and regional organizations on pertinent issues to Africa's development. NASAC's networking capacity serves as an effective resource for communicating appropriate thematic information, as well as coordinate efforts among different sectors and stakeholders in academia, policy and society. NASAC aspires to be *the voice of science* and is the affiliate network for InterAcademy Partnership in Africa.

The membership of NASAC consists of duly established national science academies in Africa that are merit-based, independent, non-governmental, non-political and non-profit scientific organizations. Through its members, NASAC seeks to enhance collaboration and knowledge sharing among scientists by using evidence-based research to African development policy in the domains of social, natural and economic sciences. NASAC aspires to make science academies in Africa vehicles of positive change for science itself, policy and societies. In so doing, academies ensure that science contributes to realizing Africa's full potential and sustainable development.

NASAC's is dedicated to enabling and inter-connecting African science academies to contribute to science, technology and innovation, to make the *voice of science* heard by African and global decision and policymakers, and to establish a culture of science in the continent.

As an independent consortium of science academies, NASAC continues to unite and strengthen its membership to address challenges on the African continent using scientific knowledge and innovative expertise. Specifically, NASAC has continued to provide advice to regional bodies and organizations on science-related issues of importance to Africa's development through its membership. It has also enhanced the capacity of academies in Africa to improve their role as independent science advisors to governments and to strengthen their national, regional, and international functions. In turn, this has assisted the scientific community in the continent to set up national independent academies or associations of scientists where such bodies do not exist. The main goal of NASAC has remained the promotion of scientific excellence so as to create a culture of science in Africa.

NASAC aspires to be an authoritative voice of the science community in Africa. It is therefore only as strong as its members and has remained relevant since its inception by:

I. Facilitating, through financial or technical support, the formation of science academies in countries where none exist.
II. Offering science academies a platform for interaction and collaboration with their counterparts worldwide.
III. Linking scientists and enhancing the voice in science through their national academies.
IV. Strengthening existing academies through provision of capacity enhancing resources that facilitate their operations as well as offer training opportunities to their officials and staff members.
V. Championing and facilitating effective networking of science academies by harnessing their collective strengths and enhancing their impact at national and continental levels.

For more information on NASAC, please visit www.nasaconline.org or contact the secretariat at nasac@nasaconline.org.

# Protecting human health against climate change in Africa

**Protecting human health against climate change in Africa**

**Editor**
Deoraj Caussy, PhD

**Authors**
Alo Babajide (Nigeria), Boko Michel (Benin), Beyene Negussie (Ethiopia), Canales Claudia (Switzerland) Caussy Deoraj (Mauritius) Essel Ama (Ghana), Fears Robin (United Kingdom), Kablan Armand (Côte d'Ivoire), Kado Jackie (Kenya), Kapwata Thandi (South Africa), Kunene Zamantimande (South Africa), Millar Danielle (South Africa), Murray Kris (Gambia), Ngaira Josephine (Kenya), Sabushimike Jean Marie (Burundi), Simane Belay (Ethiopia), Sojinu Samuel (Nigeria), Thiam Sokhna (Senegal), Traore Issouf (Burkina Faso), Wernicke Bianca (South Africa), Wright Caradee (South Africa), Zakari Ibrahim Sidi (Nigeria)

**Acknowledgements**
German Federal Ministry of Education and Research for financial support and Johanna Mogwitz (German National Academy of Sciences – Leopoldina) for technical support
Secretariat support for the working group was provided by NASAC offices in Nairobi, Kenya.

**Peer reviewers**
Ernest Amoussou (Benin), Krishnee Appadoo (Mauritius), Robin Fears (United Kingdom), Shabana Khan (India), Blessing Mberu (Kenya), Kris Murray (Gambia), Samuel Ochola (Kenya), Nazaire Padonou (Benin).

**Suggested citation**
NASAC (2022). *Protecting Human Health against Climate Change in Africa*. (D. Caussy, Ed.) Network of African Science Academies (NASAC) and InterAcademy Partnership (IAP). ISBN 979-8-9859206-1-1.

ISBN 979-8-9859206-1-1



NASAC
Miotoni Lane
off Miotoni Road
Karen
Nairobi
Kenya

Telephone: +254 0712 914285
E-mail: nasac@nasaconline.org
Web: https://nasaconline.org/



Copy-edited and typeset in Frutiger by The Clyvedon Press Ltd, Cardiff, United Kingdom

Printed by Pretty Paper Limited, Nairobi, Kenya.

# Contents


| | | page |
|---|---|---|
| **Foreword** | | **viii** |
| **Summary** | | **1** |
| Main findings of the NASAC report | | 1 |
| Key cross-cutting recommendations of the NASAC report | | 3 |
| **1** | **The challenges of climate change and health protection in Africa** | **7** |
| 1.1 | Introduction | 7 |
| 1.2 | Situation analysis of climate-sensitive diseases in Africa | 7 |
| 1.3 | Vulnerability to climate change | 9 |
| 1.4 | Specific challenges in health protection from climate change | 10 |
| **2** | **About this project** | **13** |
| 2.1 | Previous academy publications on climate change and health | 13 |
| 2.2 | Geography and global context | 13 |
| | 2.2.1 Scope of the NASAC inquiry | 14 |
| 2.3 | To whom is NASAC addressing these messages and why? | 15 |
| **3** | **Summary of known major health effects of climate change** | **16** |
| 3.1 | The underlying basis of climate change | 16 |
| 3.2 | The health effects of climate change | 17 |
| | 3.2.1 How exposure to climate change results in adverse health effects | 17 |
| 3.3 | Direct health effects due to climate change | 18 |
| | 3.3.1 Rise in temperature | 18 |
| | Case Study 1 Melting of ice on the Kilimanjaro mountains | 21 |
| | 3.3.2 Hydrological disasters: storms, heavy precipitation and floods | 22 |
| | 3.3.3 Interlinkage of storms, precipitation and floods | 22 |
| | Case Study 2 Devastating effects of Cyclone Idai in Mozambique | 23 |
| | Case Study 3 Vulnerability to floods and heat in Côte d'Ivoire | 23 |
| | 3.3.4 Drought | 26 |
| | Case Study 4 Tanzania: drought impacts on human health | 27 |
| | 3.3.5 Specific recommendations for hydrological disasters | 28 |
| 3.4 | Indirect health effects associated with changes in ecosystem and social dynamics | 28 |
| | 3.4.1 Food and nutrition security and agriculture | 28 |
| | Case Study 5 Vulnerability to locusts in Kenya | 29 |
| | Case Study 6 Climate services for African agriculture | 32 |
| | 3.4.2 Specific recommendations for agriculture and food security | 33 |
| | 3.4.3 Climate-sensitive infectious diseases | 33 |
| | 3.4.4 Zoonoses | 33 |
| | 3.4.5 Vector-borne diseases | 35 |
| | 3.4.6 Food- and water-borne diseases | 36 |
| | 3.4.7 Specific recommendations for infectious and vector-borne diseases | 39 |
| | 3.4.8 Non-infectious non-communicable disease threats | 39 |
| | 3.4.9 Specific recommendations for non-communicable diseases | 41 |
| | 3.4.10 Environmental toxicology: air pollution and other pollutants | 41 |
| | 3.4.11 Specific recommendations for air pollution | 47 |

3.5 Indirect impacts of climate change through societal changes 48
3.5.1 Forced migration and conflict 48
3.5.2 Mental health and post-traumatic disorders 49
Case Study 7 Criminal activity 50
3.5.3 Specific recommendations for forced migration and mental health 51

**4 How can adaptation and mitigation options protect human health in Africa? 52**
4.1 What are the existing regional risks from climate change in Africa? 52
4.1.1 Northern Africa 52
4.1.2 Eastern Africa 52
4.1.3 Central Africa 52
4.1.4 Western Africa 53
4.1.5 Southern Africa 53
4.1.6 Small Island Developing Island States 53
4.1.7 Summary of vulnerability across the African regions 54
4.1.8 Specific recommendations for existing climatic vulnerabilities in Africa 54
4.2 Have we reached tipping points in our existential risks? Mapping the future 56
4.3 How will developing pathways influence future scenarios? 57
4.4 What approaches do we have for adaptation and mitigation? 58
4.4.1 Adaptation for immediate health protection 58
4.4.2 Mitigation for immediate and long-term health protection 59
4.5 What are our existing challenges to adaptation and mitigation? 61
4.5.1 Policy on climate change ensures continuity of actions 61
4.5.2 Existing policy framework on the African continent 61
4.5.3 Nationally Determined Contributions for reducing greenhouse gas emissions 61
4.5.4 National Adaptation Plan for incorporating health in Nationally Determined Contributions. 62
4.5.5 Intersectoral collaboration is critical for developing Nationally Determined Contributions and National Adaptation Plans 62
4.5.6 The double challenge of adaptation and mitigation in the face of the COVID-19 pandemic 64
4.6 System approach to developing coherent strategies: identifying synergies, disconnects and inadvertent consequences 65
4.6.1 Capitalising on synergies 65
4.6.2 Avoiding disconnects as an unintended consequence 66
4.7 Wider economic and development consequences 66
Case Study 8 Economic impacts of climate change in Benin 68
4.8 Conveying the urgency of the challenges: tackling barriers to implementation 70

**5 Conclusions and recommendations 71**
5.1 What do we know and how do our recommendations address these concerns? 71
5.2 How can we address the identified challenges? 73
5.3 Generating and using the evidence base 74
5.3.1 Filling knowledge gaps by research 74
5.3.2 Improving monitoring and integration of data sets 74
5.3.3 Galvanising international partnerships to meet the challenges of climate change 74

5.3.4 Mainstream health in all policies 74
5.3.5 Promote health risk communication 75
5.3.6 What is the continuing role of academies? 75

**Appendix 1 Working group composition 77**

**Appendix 2 Supplementary tables 78**
6.1 Summary of exposure pathways and health effects of major air pollutant 78
6.2 Health impacts of climate change affect vulnerable groups 79
6.3 Summary of main policy on climate action in Africa 80

**7 List of Tables 81**

**8 List of figures 82**

**9 Abbreviations 83**

**10 References 84**

# Foreword

'Africa remains the most vulnerable continent when considering the effect of climate change, despite being the least emitter of greenhouse gases' has been aptly said by Professor Mostafa, the previous chair of the Network of African Science Academies (NASAC). The focus of the global community is the recommendation of the UN Climate Action Summit of September 2019, after the COP21 Summit of December 2015, purporting 'climate change is the defining issue of our time and now is the defining moment to do something about it'. Recognising the gravity of the situation, previous work by NASAC has highlighted climate change adaptations and resilience in Africa and a separate publication has characterised the changing disease patterns in Africa ('Changing Disease Patterns in Africa: Recommendations to Policymakers'; http://nasaconline.org/wp-content/uploads/2016/09/Changing-Disease-Patterns-in-Africa-Recommendations-to-Policymakers.pdf).

In the present report we combine the two previous recommendations into a single compilation and update the most recent developments in the field for ready use by policy-makers in Africa. There is growing evidence from reports of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) that climate change is having detrimental effects on the health of the African population and is in turn cascading into other sectors such as agriculture and food security, thereby adversely affecting livelihood, food security and the economy. We review current evidence for the detrimental health effects and chart a way of reducing these effects through mitigation and adaptation measures using innovative indigenous approaches in Africa. Climate change differentially and adversely affects vulnerable populations across the continent; we draw attention to this vulnerability and suggest ways of coping with it.

For substantial progress to be made in reducing the adverse health impacts, the root causes of climate change and its impacts must be addressed at policy levels. However, policy-makers in Africa have not been adequately sensitised to implement changes to protect human health from the adverse effects of climate change. Health effects resulting from climate change will undermine attainment of the UN Sustainable Development Goals (SDGs). SDGs are tied to climate change: for example SDG 13 calls for climate action, while SDG 2 calls for zero hunger and SDG 3 calls for good health. Monitoring of SDG performance shows many African countries are trailing behind in attaining the set goals and indicators, and if climate change is not addressed at the policy level it will further exacerbate the situation and render attaining SDGs difficult. This will negatively affect economic development, which will have a spiral effect on health.

Our objectives can be briefly summarised as follows:

1. Make best use of the current evidence base to formulate policy on climate change and health in a coordinated and harmonious manner for the whole of Africa to address urgent actions on climate change adaptation and mitigation and to raise the visibility of human health as major concerns.
2. Highlight the existing knowledge gaps and raise call-to-action research to fill them.
3. Improve health risk communication at all levels from grass-root to policy levels.

Our conclusions resound with what has been echoed in the field by the UNFCCC, World Health Organization (WHO) and the *Lancet* Commission, among others. These sources are used as the basis for understanding the situation in Africa and are discussed extensively in the ensuing chapters. Our contribution is aimed at adding value to the existing knowledge base by synthesising a single report that incorporates the plethora of information. We highlight the fragmented and missing knowledge gaps as an impetus for action, presenting opposite views and synchrony where they exist. This is done by considering the core values of academies of being free of vested interest and accountable to society as beacon of truth. In doing so, we aim to catalyse and spur further discussions and actions among academies, the scientific community, relevant stakeholders and policy-makers at national and Africa-wide levels.

The present report was written after consultation with a group of experts nominated by the NASAC's member academies. Through their cooperation between NASAC and the German National Academy Leopoldina, top African scientists with expertise on this topic agreed to review the existing evidence base on climate change and health in Africa, and to revisit the adaptation question and assess the mitigation strategies to produce a set of recommendations. I convey my thanks to everyone who has contributed to this project, in particular the German Ministry of Education and Research for technical and financial support.

We welcome discussions on any points arising from our report.

Professor Mahouton Norbert Hounkonnou
President, NASAC

# Summary

The synthesis report of COP26 illustrates the compelling evidence linking climate change and health supported by leading climate scientists from around the world (IPCC, 2020). Considering the gravity posed by Africa being the most vulnerable continent for adverse effects on health, leading scientists from Africa, under the aegis of the Network of African Science Academies (NASAC), critically reviewed the evidence linking climate change to health in Africa and formulated evidence-based recommendations to mitigate and adapt to the threats of climate change that can be viewed as a health disaster in the making. If these threats are not addressed now, climate change will destroy the lives and livelihoods of millions of Africans and impede future development on the continent.

NASAC's objectives in this project are to advise on the following aspects:

1. To assess the status of climate change and its adverse health consequences in order to make policy-level recommendations that African governments should consider when dealing with climate change and resilience in Africa.
2. To advocate evidence-based policy and practical solutions for climate change mitigation and adaptation strategies.
3. To identify and prioritise existing knowledge gaps with respect to the risks to health and to promote research to fill the knowledge gaps and find solutions for the following questions:
   (a) What are the levels of risks?
   (b) What are the major associated health risks?
   (c) Who are the vulnerable populations?
   (d) Under what conditions are vulnerable communities exposed to climate change?
4. What are the tipping points beyond which irreversible changes will occur?
5. How can we balance economic development with health protection in all sectors so that there is synchrony in building a resilient health system?

Previous work by NASAC has highlighted climate change adaptations and resilience in Africa, and a separate publication has characterised the changing disease patterns ('Climate Change Adaptation and Resilience in Africa: Recommendations to Policymakers'; http://nasaconline.org/wp-content/uploads/2016/09/Climate-Change-Adaptation-and-Resilience-Recommendations-to-Policymakers-WEBi.pdf). In the present report we extend our work into a single compilation on climate change and health, and update the most recent developments in the field. The information contained in this report provides African governments with an important knowledge base for formulating their national policies and stating their positions in international climate change negotiations. Climate change is being addressed in Africa by various organisation including the World Health Organization (WHO), United Nations Framework Convention on Climate Change (UNFCCC), African Union (AU) and others. Ours is a synthesis report specifically focusing on climate change and health in Africa. NASAC's main messages, based on our assessment, are as follows.

## Main findings of the NASAC report

- *The African continent is the most vulnerable to the adverse health effects of climate change*

The vulnerability of the African continent to the adverse effects of climate change stems from four fronts: (1) physical factors imparting its unique topology and climate; (2) the high prevalence of climatic hazards; (3) pre-existing disease that could potentially be amplified by climate change; (4) its health systems are not resilient enough to cope with the accrued burden of climate-sensitive diseases; and (5) poverty levels and other social determinants of vulnerable groups that confer on them inadequate adaptive and coping mechanisms. In combination, these factors confer a high vulnerability to adverse effects of climate change.

- Physically, Africa consists of 60% of dry land mass; 38% of which is desert and crossed by the Equator and both Tropics, conferring a variety of climates and topologies with varying vulnerability to adverse effects of climate change.
- The continent has a high prevalence of climatic hazards marked by rising temperature and sea levels and extreme weather conditions increasing the risk of hydrological disasters, forest fires, and air and water pollutants.
- The disease burden due to climate change is the highest in the world, with roughly 120 deaths per 1 million inhabitants annually. This burden comprises heat-related complications, drought, floods, famine, malnutrition, non-communicable diseases (especially stroke) and mental health issues such as being demoralised as a result of climate change. The projections for these conditions and other climate-sensitive adverse effects such as vector-borne diseases and air pollution are dire.
- The health system is not resilient enough to cope with any surge in the burden of diseases, as amply illustrated during the continuing outbreaks of Ebola virus, influenza and the ongoing COVID-19 pandemic.
- Poverty, lack of infrastructure and other social determinants undermine the coping capacities of vulnerable populations.

- *Climate change is happening now in Africa, and its impacts are already being felt*

There is strong evidence that warming over land across Africa has increased over the past 50–100 years and climate change has already altered the magnitude and frequency of some extreme weather events in Africa. This is amply illustrated by temperature rise melting the icecap of the Kilimanjaro mountains; the increased droughts recorded in countries of Western Africa; periodic flash floods observed in Central Africa; and sea-level rise leading to coastal erosion in Northern and West Africa.

- *Further climate change is inevitable in the coming decades*

Modelling shows that the temperatures on the African continent are likely to rise more quickly than in other land areas, particularly in the more arid regions of central and Southern Africa, leading to desertification. Extreme weather is projected to lead to more frequent cyclones in Eastern and Southern Africa, as has already been observed in the past decade.

- *The health, livelihoods and food security of people in Africa have been affected by climate change*

Climate change will invariably result in an increase in climate-sensitive diseases, leading to deaths in many cases or severe disability and mental health. The climatic hazards may act singly or in various combinations to have a cascading effect from one sector to another. Climate change will alter the incidence and geographic range of vectors and concomitantly vector-borne diseases. In addition, climate change will create pressure on water resources; consequently, reduced crop productivity, leading to food insecurity may be further aggravated by crop failure due to drought, floods and pest infestation.

- *Climate change also challenges growth and development in Africa*

The United Nations Sustainable Development Goals (SDGs) are linked and inherently affected by climate change. The COVID-19 pandemic has already adversely affected the health and economies of Africa. The convergence of adverse effects of climate change and the COVID-19 pandemic will affect fundamental social and economic policy goals such as growth, equity and sustainable development.

- *Data on climate change in Africa are dispersed and scanty*

Although the evidence for climate change and its adverse effects is compelling, precise information on the prevalence of climatic hazards and diseases over extended periods and regions is scanty and dispersed and the most poorly characterised of all continents. Although most African countries have instituted integrated disease surveillance with help of the WHO, event-based surveillance using the EWARS[1] method is virtually non-existent for climatic hazards and climate-sensitive diseases There is limited information on data gathered from national government sources. In synthesising our evidence, we used various sources ranging from case studies, anecdotal data, research to projections; all are in urgent need of being updated.

- *Statistical modelling supports the role of adaptation and mitigation in reducing the impacts of climate change in Africa.*

The impacts of adaptation and mitigation measures for selected climatic hazards such as heat, diarrhoea and malnutrition, vector-borne diseases and non-communicable diseases have been characterised specifically for the African continent to the year 2030 and beyond. All the evidence points to the fact that timely implementation of adaptation and mitigation measures will considerably save lives and livelihood.

- *Health adaptation and mitigation are not adequately planned in Africa*

Over the past decade, many countries across Africa have adopted increasingly comprehensive development plans with ambitious social and economic development objectives. Several African governments, such as Ethiopia and Rwanda, have adopted national climate-resilience strategies with a view to applying them across economic sectors. Although most African countries mention health in their Nationally Determined Contributions (NDCs), in practice very few have included a strategic plan for the health component in their National Adaptation Plan (NAP), resulting in insufficient climatic actions for health protection.

- *International cooperation to avert adverse climate change is limited in Africa.*

Several UN agencies including the UNFCCC, United Nations Environment Programme (UNEP) and WHO are involved in climate actions in Africa. However, there is a dearth of international non-governmental organisations, international research institutes and academia supporting the fight against climate change in Africa.

## Key cross-cutting recommendations of the NASAC report[2]

On the basis of the evidence reviewed in this report, including that from the case studies, and considering previous work in this field, the working group formulated the following recommendations.

1. *Policy*. Climate policy is central to guiding programmatic actions and ensuring consistency and continuity. Although many international and regional policies are available to planners, to ensure inclusion of the health component in climate change, a national policy is of paramount importance.
   - Update policy to reflect emerging and current issues or expected pathways on national climate change and health.
   - Incorporate health in the Nationally Determined Contribution (NDC) during formulation of the national health adaptation plan as proposed by the Libreville Declaration. This will ensure inclusion of the health ministry in planning, monitoring and accessing available climate funds.
   - Conduct/complete the Situation Analysis and Needs Assessment (SANA) process to integrate health National Health Adaptation Plans (NHAPs) of all African countries, as recommended during the Paris Agreement.
2. *Intersectoral collaboration*. Since the NDC is usually undertaken by the Ministry of Environment, while the National Adaptation Plan (NAP) is usually

[1] EWARS, early-warning system, a tool for surveillance.
[2] These recommendations are further elaborated in the appropriate sections of the report.

undertaken by the Ministry of Health, the health component of climate change is either missing or incomplete.
- Promote intersectoral collaboration across sectors at all stages from planning and implementation to monitoring and evaluation.
- Mainstream the WHO Health in All Policies (HiAP) tool.
- Promote the joint WHO–FAO, one-health approach to avert risk in agriculture and manage climate-sensitive zoonotic diseases.

3. *Data for policy and programmes*. Policy-makers, scientists and all relevant stakeholders need information for designing policy, implementing and monitoring programmes and setting priorities.

- Roll out a robust database for collecting and analysing information on the prevalence of climatic hazards, their exposure pathways and related health conditions.
    - The climatic hazards of concerns for Africa include air and water quality, temperature and ocean rise, and extreme weather in the form of droughts, floods and storms.
    - Monitor ecological contamination of air and water media to detect toxic levels of air pollutants responsible for respiratory health conditions and water-borne diseases causing diarrhoea and infant mortality after flooding.
    - Institute the early-warning system of surveillance (EWARS) on vectors that may be amplified by climate change to avert outbreaks of climate-sensitive diseases such as malaria and other vector-borne and zoonotic diseases.
    - In countries where a systematic database cannot be implemented immediately, an early-warning system aiming at a climate-related event base surveillance system may be explored.

4. *Capacity building*. Africa needs a critical mass of climate scientists who are well versed in policy, programmes and research and who can play important roles in the field and lead climate science in the region. To reach these goals, we make the following recommendations.

- Train policy-makers and government officials in the basics of climate change, policy-making, implementation, climate activity financing and emerging issues such as NetZero carbon policy to be able to negotiate at national, regional, and global levels and access various funding sources including the Green Climate funds and Africa–European Union collaboration.
- Produce graduate-level scientists qualified in climate change to manage the imminent crisis in Africa.
- Train climate scientists, health-care workers including practitioners to monitor epidemiological trends in climate-sensitive diseases, as well to detect, monitor and manage such diseases.

5. *Research*. Policy-makers need basic information generated within the African continent to make important decisions on choosing the best control strategies. Much international research on climate change in Africa is constrained by the lack of mutual agenda setting and benefits, and equality in decision-making between partners. This disequilibrium must shift to build research capacity.

- Foster formal arrangements with various partners such as the WHO Regional Office for Africa and the African Union. The Network of African Science Academies with its all its member academies should be supported to promote research.
- Research should, *inter alia*, be directed to fill the gaps in the dearth of information on the prevalence of climatic hazards in time and space; link disease mortality with exposure; elucidate the complex causal exposure pathways; and demonstrate the economic and health co-benefits of various adaptation and mitigation strategies.

6. *Health adaptation*. To avert and minimise the immediate adverse effects of climate

change, protective actions must be implemented by communities, some of which are evident from the case studies in this report.

- Incorporate adaptative measures including EWARS in the national climate policy to detect warning signals due to climate change and adverse effects.
  - Develop EWARS for heatwaves, hydrological disasters, vector controls and climate-sensitive diseases.
  - Develop strategies for coping with surges in adverse health impacts.
  - Anticipate and support vulnerable communities.

- Empower indigenous communities with the basic science of climate change to enable them to incorporate their knowledge into agricultural and cropping practices, including exploiting the planting of fire-resistant trees to limit forest fires, and drought- and pest-resistant crops to increase yields.
- Promote switching traditional cooking practices from biofuel to cooking stoves to reduce indoor air pollution.
- Encourage all communities to adapt their diets from high animal-based protein to plant- and insect-based protein.

7. *Mitigation*. While adaptation measures provide immediate relief from the adverse effects of climate change, eventually these adverse effects overcome the adaptation measures and necessitate mitigation measures to reduce the carbon sink.

- Formulate and mitigate national mitigation strategies to reduce the carbon sink by incorporating it into NDCs.
- Reduce greenhouse gas (GHG) emissions across sectors that are big polluters, for example in urban transport, agriculture and forestry.
- Promote urban green spaces for planting trees to mitigate the effects of urban heat islands.
- Incorporate and sustain green technologies in post-COVID-19 recovery innovative technologies.
- Africa stands to benefit from integrated climate adaptation, mitigation and development approaches.
- In expanding economically and meeting their development needs, African countries have abundant opportunities to adopt clean, efficient low-carbon technologies and practices.
- Some low-carbon development options may be less costly in the long term and could offer new economic opportunities for Africa.
- Many of the measures to avoid GHG emissions provide generous gains in economic productivity, human development and quality of life. The adoption of a low-carbon pathway needs to fit into countries' specific national circumstances.
- Integrate adaptation and mitigation strategies into short- and long-term development planning. Short-term measures include integrating climate adaptation and disaster risk reduction, while long-term mitigation measures require, governments, businesses and communities to prepare for climate impacts by reducing the carbon sink.

8. *Advocacy*. Awareness about climate change and health must be raised to set the public agenda and bring the issue to the attention of policy-makers and implementers.

- Simplify climate change science including adaptation and mitigation measures to influence the social behaviour and practices of institutions and individuals.
  - Promote system dynamics and a participatory approach by engaging lay citizens, school children and youth to capture their innovative approach and guarantee the future of Africa.
- Target health risk communications to counter misinformation on climate change and health.
- Educate primary health care and community-level doctors in climate change, to make significant strides in advocating citizens to adopt lifestyle changes that

limit carbon emissions and achieve better health.

9. *Partnership*. The agenda to avert the adverse health effects of climate change in Africa calls for substantial investment in knowledge, infrastructure, and human and financial resources. Climate change is a shared global problem that lies outside the political reach of any one nation state and requires a collective, global response. Therefore, international cooperation is vital to avert dangerous climate change.
   - Forge multidisciplinary and transdisciplinary engagement at national, regional, and global levels.
   - There is an urgent need to support Africa in dealing with its disproportionately high disease burden in relation to the low amount of GHGs. The European Union–Africa Green Climate cooperation is an exemplary initiative and may be replicated with developed countries, where most of the GHGs are produced.
   - Link climate action with specific provisions of SDGs, the New Urban Agenda, WHO Urban Health Research Agenda, AU Agenda 2063 and other regional networks such as the Southern African Development Community (SADC) and the African Continental Free Trade Area (AfCFTA).

# AUTHOR QUERY FORM

Dear Author,

During the preparation of your manuscript for publication, the questions listed below have arisen. Please attend to these matters and return this form with your proof.

Many thanks for your assistance.

| Query | References Query | Remarks |
|---|---|---|
| 1 | AUTHOR: "Azongo et al., 2012" has not been included in the Reference List, please supply full publication details. | |
| 2 | AUTHOR: "Diboulo et al., 2012" has not been included in the Reference List, please supply full publication details. | |
| 3 | AUTHOR: "Egondi et al., 2012" has not been included in the Reference List, please supply full publication details. | |
| 4 | AUTHOR: "Al-Hamndou, 2014" has not been included in the Reference List, please supply full publication details. | |
| 5 | AUTHOR: "Beguin et al., 2014" has not been included in the Reference List, please supply full publication details. | |

# 1 The challenges of climate change and health protection in Africa

## 1.1 Introduction

Climate change is happening now in Africa, and it is threatening the lives and livelihoods of millions of Africans and undermining development goals of many African nations. Hence a sense of urgency is warranted to curb these negative effects through adaptation and mitigation measures. Climate change results either from natural factors or from anthropogenic activities producing greenhouse gases (GHGs) (USEPA, 2014). Collective anthropogenic activities including burning of fossil fuels, deforestation or intensive farming release excess GHGs. The GHGs amplify the warming effects globally including the African continent, resulting in measurable adverse climatic conditions such as temperature and ocean rise as well extreme weather conditions (Solomon, 2007). Climate change directly or indirectly causes numerous health effects, as elaborated in chapter 3. The health effects are not uniformly distributed in proportion to the amount of GHGs produced by Africa; rather, it is determined by the existing and potential vulnerabilities of the African population. The African continent, for example, contributes less than 20% of the global output of GHGs yet it bears the highest burden of health impacts of climate change (World Health Report 2002).

## 1.2 Situation analysis of climate-sensitive diseases in Africa

Compared with the rest of the world, the African continent has the highest burden of mortality due to climate change (World Health Report 2002). As documented in chapter 3 (Figure 3.1), the World Health Organization (WHO) estimated that between 80 and 120 climate-related deaths occur per 1 million people every year in Africa. Various subsequent studies or projections have corroborated the staggering number of deaths, illnesses or injuries due to climate change. This disease burden maybe apportioned to (1) the direct impacts of climate change associated with exposure to extreme weather conditions such as heatwaves, drought, flash floods and rising sea levels; (2) the indirect impacts of climate change can be due to alterations to our ecosystem, affecting water and air quality, or causing disequilibrium of vectors and vector-borne diseases, as well changing agricultural patterns; and (3) indirectly, climate change leads to forced migration when populations are demoralised because of loss of lives, livelihoods and properties. Since the exposure pathways are multiple, the exposed population may invariably experience the direct and indirect impacts simultaneously. These health impacts and their exposure pathways are elaborated in chapter 3. Here we review the main burden of climate-sensitive diseases that are prevalent in Africa.

*Heat-related disorders, including heat stress*. As climate warms, many Africans could be susceptible to heat-related illness and disorders including stroke and cardiovascular diseases. Although specific heat-related mortality data are not available for all countries in Africa, a study from South Africa shows that for every 1 °C temperature rise, the mortality increases by 1% in the general population and by 2% in those older than 65 years. Similarly, other time-series studies from Burkina Faso, Ghana and Nairobi also support an association between rising temperature and daily mortality rate especially for the under-5 age group (Azongo *et al*., 2012; Diboulo *et al*., 2012; 1 2
Egondi *et al*., 2012). Since many parts Africa 3
lie in the equatorial and desertic zones, the actual number of mortalities is expected to be high. Quantitative risk assessment modelling by the WHO for a scenario with no adaptation measures forecasts an additional 7,387 heat-related deaths by the year 2030 for sub-Saharan Africa (WHO, 2014). This increase will not be evenly distributed: countries within the hot zones such as sub-Saharan Eastern and Western zones are projected to have a higher mortality than cooler regions such as Northern Africa.

Heat rise can lead to loss of productivity for those who work outdoors. A study from South Africa demonstrates that heat rise may reduce labour productivity by nearly 60%, with far-reaching economic consequences (Kjellstrom, 2014). Temperature rise in Africa is also causing the icecaps to melt in the Kilimanjaro mountains, forcing rivers to change their course and affecting the agricultural patterns of villagers.

*Health impact of hydrological disasters*. Hydro-meteorological impacts of climate change resulting from floods, droughts, cyclones, storms, hurricanes, tornadoes, snow and fog cause widespread destruction, injuries and deaths. Droughts and floods account for over 80% of human deaths and 70%
4 economic loss in Africa (Al-Hamndou, 2014). The countries most affected by frequent weather events between 2000 and 2019 include Kenya (60 events), Mozambique (55 events), South Africa (54 events), Nigeria (49 events), Ethiopia (43 events) and the Democratic Republic of the Congo (41 events). In Mozambique, the flood in 2000 and two cyclones caused 800 deaths. In March 2019, Cyclone Idai caused the deaths of 602 people in Mozambique and 299 people in Zimbabwe, making it the deadliest storm on record to strike Africa. In 2019, over 1,200 people lost their lives because of cyclones, floods and landslides in Kenya, Malawi, Mozambique, Somalia and Sudan. Apart from deaths and injuries, hydrological disasters such as floods lead to contamination of water resulting in food- and water-borne diseases. In sub-Saharan Africa an estimated 91 million episodes of food-borne diseases are reported annually (WHO, 2015a). Similarly, for water-borne diseases an estimated 1 in 10 children died from diarrhoea in 2016, accounting for an estimated 25 million disability-adjusted life-years. According to WHO projections an estimated 67,000 deaths due to malnutrition will result by the year 2030 if no adaptation and mitigation measures are implemented.

*Respiratory diseases and disorders including asthma and allergies*. Climate change associated with increased outdoor ambient and indoor air pollutants is already negatively impacting the respiratory health conditions of millions of Africans. Climate change and air pollution are interrelated especially in the ambient environment: anthropogenic activities of burning fossil fuels release pollutants in the air and lead to climate change. The continent is undergoing both environmental and epidemiological transitions: there is a shift in the types of air pollutant from a pattern of predominantly indoor air to one of outdoor air pollution. This is due to rapid urbanisation and high traffic volumes coupled with high population densities. Air pollution is now the second largest cause of deaths in Africa, exceeded only by AIDS (acquired immunodeficiency syndrome) (GDB, 2019). The African continent accounted for 16.3% of global deaths due to all air pollution in 2019, representing some 1.1 million deaths in Africa alone (Fisher *et al*.,2021). The main causes of deaths attributable to air pollution were lung cancer, chronic obstructive pulmonary diseases and stroke (WHO, 2020).

*Vector-borne* diseases. A warmer climate and changing rainfall patterns may extend the geographical zones and breeding patterns of mosquitoes, ticks and other climate-sensitive vectors. Malaria, which is transmitted by mosquito vectors, is of considerable public health importance in Africa, accounting for some 92% of global
cases and deaths in 2019 (Beguin *et al*., 5
2014). Climate change will invariably intensify malaria transmission in the highland regions of Africa including Kenya and Ethiopia (Siraj, 2014). Statistical modelling shows that some 771 million persons will be at risk of malaria in sub-Saharan Africa (WHO, 2020a). But this increase will not be uniform across sub-Saharan Africa, because climate change associated with reduced rainfall may also limit the spread of malaria in southern sub-Saharan Africa (Hay *et al*., 2002). Other vector-borne diseases that are likely to be amplified by climate change in Africa include dengue fever, yellow fever and Rift Valley fever. Since Rift Valley Fever kills both human and cattle, this

disease will affect both lives and livelihood in Africa.

*Food insecurity*. Changing rainfall patterns, variable carbon dioxide and extreme temperatures due to climate change may lead to crop failure and decrease food production (WHO, 2012). A large part of the African economy is agriculturally based, and it produces 60% of the continent's food supply. Climate-associated reduction in food production may be directly due to drought, heat, floods and pests such as locusts that are amplified by the warm temperature of climate change, or indirectly by floods contaminating water and food. Increased food insecurity is projected to cause some 67,000 additional deaths by 2030 while water- and food-borne contamination accounts for some 137,000 deaths annually in Africa. The increase in food insecurity drives the population to rely on imported energy-dense food or to resort to bio-crops such as maize which are also energy dense. This change in dietary patterns may put some 118 million Africans at risk of non-communicable diseases (NCDs) and cardiovascular disease including stroke, which is particularly fatal under rising heat conditions.

## 1.3 Vulnerability to climate change

The African continent is particularly vulnerable to the effects of climate change (Boko *et al.*, 2007; WHO 2015c). Vulnerability to climate change is the degree to which individuals or systems are unable to cope with the adverse effects of climate change (Solomon, 2007). Individual countries on the continent differ in the degree of vulnerabilities as determined by their inherent topology, geography, predisposition to climatic hazards, political governance, the underlying health profiles, health infrastructure and socio-demographic profiles. These differences impart varying degrees of vulnerability to adverse health consequences of climate change. The concept of vulnerability is elaborated in chapter 3 and appendix 2.

*Topological and geographical vulnerabilities*. The African continent covers a vast expanse of land types and climates. Some 60% of the land mass is dry land of which 38% is desert. The continent is crossed by the Equator, the Tropic of Cancer and the Tropic of Capricorn; thus, it experiences sub-tropical, tropical, equatorial and Mediterranean types of climate. As elaborated in chapter 3, there is a high prevalence of climatic hazards of rising temperatures, sea levels and adverse weather conditions. The topology of each country and the prevalence of climatic hazards confer different degrees of vulnerabilities.

*Pre-existing disease burden and non-resilient health system*. The disease burden is shifting from a high prevalence of infectious diseases to non-communicable and environmental diseases. Most African countries now face a double burden of traditional infectious diseases, malnutrition, and child and maternal mortality; and emerging challenges of chronic diseases, mental health disorders, environmental degradation and climate change (Agyepong *et al.*, 2017): The convergence of climate change and food insecurity potentially exposes some 118 million Africans to increased risk of NCDs.

In most parts of Africa, the heath system is fragmented, vertical and remains weak in health expenditure, health infrastructure and the number of health professionals in relation to the size of the population (Agyepong *et al.*, 2017). Consequently, the health system is not resilient, resulting in poor coverage and quality of services, especially during epidemics as illustrated during the Ebola disease outbreak and the and pandemics of influenza and COVID-19. The added disease burden due to climate change will overpower the already fragile health system's capacity to cope.

*The social determinants of the vulnerable population*. The groups most vulnerable to climate change are women, children (especially those under 5), elderly persons, people living in poverty, persons working outdoors, indigenous and native peoples, persons with comorbidities and disabilities, and homeless marginalised groups. Social determinants are the factors that define where a person is born, brought up, works and dies. Thence the social determinants influence to what extent a particular group is vulnerable to the adverse effects of climate change. Africa is considered one of the most vulnerable continents to the adverse effects of climate change on the basis of the social determinants of the population that face endemic poverty, complex governance, limited access to capital markets and weak adaptive capacity because of lack of infrastructure and technology (Ebi *et al.* 2002.; Boko *et al*., 2007; WHO 2008). In view of these social determinant challenges for effectively adapting to climate, the adverse effects of climate change must be addressed now in a coherent manner.

## 1.4 Specific challenges in health protection from climate change

It is evident from situation analysis and vulnerability assessment of the African continent that addressing the threats posed to human health due to climate change is beset with many persistent challenges. These are discussed below.

*Limited climate-related policy at the national levels*. Health protection policy for climate change, in the form of laws, regulations and guidelines, is the cornerstones for guiding and implementing climatic actions. Two commonly used robust tools for policy formulation of climate actions are the Nationally Determined Contribution (NDC) and National Adaptation Plan (NAP), as jointly recommended by the WHO and United Nations Framework Convention on Climate Change (UNFCCC) (see section 4.5 for further details). The NDC contains climate-related policies and targets aimed at reducing GHGs and adapting to their adverse effects, while the NAP subcomponent contains the National Health Adaptation Plan (NHAP), which addresses health affect assessment, mitigation, adaptation and financial supports for health system strengthening.

The challenge of integrating the health component into the NDC is a persisting one: various studies have shown that although most countries in Africa have formulated NAPs and many mention health in them, very few have formulated a public health adaptation plan in the NAPs or have been able to access international climate funds (Nhamo and Muchuru, 2019; Dasandi *et al*., 2021). Some potential explanations for these bottlenecks are (1) the health community being excluded or absent from the NAP process; (2) the health sector not submitting proposals to the NDC; (3) the proposals on health adaptation not meeting the minimum technical requirements; or (4) the process of arriving at an NHAP from the NDC may be lengthy, cumbersome and outside the technical capacity of many African countries.

*Inadequate infrastructure and experts*. Existing policy without enabling infrastructure is of limited use in combating the adverse effects of climate change. The health system is the main infrastructure for responding to climate change; it must be resilient and able to manage health in normal and unusual situations. The health system must be endowed with health-care workers who are specifically trained to recognise, monitor and manage climate-sensitive disease. Africa has an acute shortage of human capital to manage the upsurge of climate-related diseases and conditions; consequently, many conditions go undetected which adds to the existing high disease burden and mortality.

*The challenges of working across sectors*. Public health adaptation to climate change is a joint commitment of the ministries of health and environment. NDC formulation in Africa is based on the Libreville Declaration between the WHO and United Nations Environment Programme (UNEP), which calls for intersectoral collaboration. Therefore, this process ensures synergies between health and other sectors and increases the co-benefits of adaptation and mitigation measures. Despite the Libreville Declaration, surprisingly enough not all countries in Africa have formulated their NAP or HNAP in collaboration with their health sectors. Reducing the health impacts of climate change is an exercise that cannot be done in isolation. Many of the mitigation measures are outside the scope of health ministries and there is often little or no intersectoral collaboration with non-health ministries, or vice versa. Intersectoral collaboration can be promoted by the WHO guideline on Health in All Policies (HiAP); again, however, there is limited capacity to introduce HiAP into programmes because of lack of expertise.

*Insufficient evidence base*. Although the global evidence for climate change and health is compelling, policy-makers demand and require evidence derived from African studies. Sadly enough, there is a dearth of such information; much evidence is extrapolated from studies done in other parts of the world. In the absence of country-specific evidence, policy-makers may be reluctant to invest in climate change and health or may completely reject the causal association of climatic hazards linked to adverse health effects in our continent.

*Finding practical adaptation and mitigation strategies*. Adaptation and mitigation are our only control strategies to curb the adverse health effects of climate change. For the health sector, public health adaptation consists of taking short-term measures aimed at minimising exposure to climatic hazards, reducing vulnerability and building capacity. These could be done by setting up early-warning systems (EWARS) to monitor climatic hazards in an effort to minimise or reduce exposure. Vulnerability could be decreased by adaptive measures that empower the exposed community in knowledge and practice. Capacity building requires strengthening the health system for resilience. Although each of these adaptive measures can be implemented with financial support, adaptation eventually becomes ineffective in the face of rising GHGs that require mitigation measures to curb toxic levels. Mitigation and switching to green technologies are viable options but they require substantial human and financial resources beyond the capacity of most African countries, especially when recovering from the COVID-19 pandemic. In recovering from the COVID-19 pandemic, African nations have some hard choices to make on whether to choose adaptation with immediate relief or long-term, costly mitigation. Africa has appreciable reserves of fossil fuels amounting to 9.5% of global crude oil reserves, 8% of natural gas reserves and 4% of coal reserves (BP, 2012). Since there is limited hard evidence on the co-benefits of green technology, most countries are locked in their dependence on fossil fuels.

*Bridging the inequity gaps and attaining SDGs*. Vulnerable groups comprising women, children and outdoor workers are those that suffer most from social inequity on account of their ethnicity, living in rural areas and absence of education. Climate change will disproportionately affect these groups, and this will undermine the attainment of the WHO Universal Health Coverage (UHC). The attainment of UHC is one of the key health targets in the SDGs. Health is inextricably linked to development and therefore climate change may have profound socio-economic impacts on African countries that are striving towards socio-economic development and meeting the challenges of attaining the SDGs (WHO, 2008, 2015b, 2015c). The SDGs that are interrelated with each other are SDG 13, which focuses on climate change actions; SDGs 1, 3 and 10, which *inter alia* aim at meeting the UHC goal. Since the SDGs are interlinked, integrated, indivisible and universally applicable, if one fails in reducing the adverse effects of climate change then the others will also be adversely affected.

*Partnership*. The body of evidence derived from the situation analysis and the daunting challenges show that most countries in Africa are unable to meet the challenges of climate change and health due mainly to lack of human and financial resources. Meeting the challenges of climate change is a tall order requiring partnership and cooperation at the global level. Climate actions are being undertaken by non-governmental organisations and overseas institutions, usually as demonstration projects. UN agencies provide guidance to some extent, but sustainable partnership is virtually absent. Unless this situation is remedied, the goal of climate change actions may not be reached soon.

# 2 About this project

The scientific communities from the Network of African Science Academies (NASAC) undertook this project of 'Climate Change and Health' which is spearheaded by the German National Academy of Sciences Leopoldina and the global network of science academies, The InterAcademy Partnership (IAP).

Policy-makers need to be appropriately briefed for implementing corrective actions as part of the global initiative to avert the impending disaster of climate change and its effects on health. There exist a plethora of policy documents including those of WHO-AFRO, UNFCCC, AU, UNEP, etc., but the publications are variously scattered and are often cumbersome to digest. Policy-makers need clear and concise documents of the existing evidence on climate change and health. This regional project analyses the situation on climate change and health in Africa to produce science-based recommendations for Africa.

## 2.1 Previous academy publications on climate change and health

Academies serve as beacons for providing evidence-based scientific information on contemporary issues affecting society. In this spirit, globally academies have addressed the issue of climate change and health, starting in 2010 with the seminal work of the InterAcademy Medical Panel to the present work of NASAC. Our work builds on that of other academies on this subject include the German National Academy of Sciences Leopoldina, the Swiss Academies of Arts and Sciences, Pontifical Academy of Sciences, US National Academy of Sciences, Australian Academy of Science, Royal Society of New Zealand and the European Academies' Science Advisory Council.

Realising that climate change impacts are likely to widen existing health inequities in many domains, NASAC commissioned a report on climate change adaptation and resilience in Africa (NASAC, 2016). This report highlighted a path for the sustainable development of Africa in a changing climate, based on assessment of sectoral impacts and adaptation options offering recommendation to policy-makers. NASAC has also echoed a call to action on climate change and health in Africa in its publication '*Changing Disease Patterns in Africa*' (NASAC, 2017). It urged interdisciplinary research collaboration to collect evidence from programmes on impact, vulnerabilities and adaptation to climate change, and on the complex interactions with multiple other determinants of stress and disease throughout Africa (NASAC, 2018).

## 2.2 Geography and global context

The present remit of NASAC is to focus on health protection from climate change on African society, health and economies, which are covered in the following chapters. Climate change is intimately linked to globalisation and has economic and health implications for Africa (McMichael, 2013). As discussed in section 3.1, human health is dependent on the Earth's natural biophysical system. Hence the influences of globalisation in the African context must be addressed collectively. Admittedly, not all regions of Africa are homogenously vulnerable to the effects of climate change. However, because of transboundary pollutants, neighbouring countries are interconnected and consequently all of Africa is at risk from the impacts of greenhouse gases.

Climate change cannot be addressed within the boundary of a nation alone; it is a global and regional issue. Policy-makers in Africa need to be briefed that climate changes in Africa or the rest of the world are interlinked through the movement of goods and services which may act as agents of climate change and its associated negative impacts. In 2009, the Global Health Commission on Climate Change called climate change 'the biggest global health threat of the 21st century' (Costello *et al.*, 2009). The WHO estimates that 'climate change will cause and additional 250,000 deaths per year from 2030 to 2050' potentially through malnutrition, malaria, diarrhoea and heat exposure associated with climate change (WHO, 2014). Therefore, understanding and tackling climate change globally is important for addressing sustainable development goals (SDG's) collectively in supporting Africa and international development agencies in promoting security for the population in Africa.

Our rationale for undertaking this project is predicated on the following premisses:

- Climate change effects on health, discussed in chapter 3, transcend geographical and political boundaries.
- The body of growing evidence supports the link between climate change and population in Africa, with increasing population movement and forced migration, as discussed in section 3.
- Africa is vulnerable to disruption of trade food supplies and other non-agricultural commodities and raw materials needed for manufacturing and goods; climate change may lead to interruption in supply chains.
- Adopting climate-smart adaptation and mitigation in Africa brings opportunities for entrepreneurial activities and economic development.
- The consequences of global changes affect Africa, common African citizens and companies operating in Africa.

### 2.2.1 Scope of the NASAC inquiry

The focus of the NASAC inquiry is to use evidence-based assessment to inform policy options and, where such information is missing in the African continent, to highlight the gap to be filled. We start with the situation analysis and a review of the challenges besetting health protection in Africa, covered in chapter 1. In chapter 3, we present a succinct view of the current state-of-the-art evidence on health effects, reviewed by specialists in their field and where necessary drawing parallel corroborating evidence from other parts of the world, namely Europe and America, that have spearheaded the field of climate change and health. This inquiry attempts to answer two fundamental questions, which are shown in the boxes 2.1 and 2.2. (1) What are the known health effects, as described in chapter 3? (2) What are the main adaptation mitigation strategies to safeguard health, as described in chapter 4? In chapter 5 we formulate key recommendations for urgent attention in the African continent.

Our main objectives in this report are the following:

- Use the transdisciplinary strengths of the African academies to conduct a situation analysis of climate change and health.
- Extend the discussions on climate change and health across Africa and generate greater understanding of the health effects

**Box 2.1 Key questions on the health effects of climate change to be answered in chapter 3**

1. What are the major health effects?
2. Who is vulnerable and where do they live?
3. Are there tipping points beyond which major, and perhaps catastrophic, effects could occur?
4. Over what time will major effects take place?
5. How will development pathways modify the effects?

**Box 2.2 Key questions on the main adaptation and mitigation policy options to safeguard health to be answered in chapter 4**

1. Which policies increase resilience?
2. Which is the best combination of adaptation strategies, and in which context?
3. What are the most important health benefits of mitigation strategies in the key sectors of energy, housing, planning, food and agriculture, industry, etc.?
4. Are there unintended consequences?
5. What are the barriers to implementation and how can they be overcome?

resulting from climate change and the health co-benefits of decarbonisation.

- Provide advice to inform sustained, coherent and coordinated policy development and decision-making across a broad front; this includes strengthening research and surveillance, finding optimal ways to implement a public health package for immediate adaptation, together with monitoring of implementation activities and their impacts.
- Support efforts to improve public engagement including follow-up by the member academies of NASAC to use this report as a resource to engage with civil society.

## 2.3 To whom is NASAC addressing these messages and why?

*Policy-makers, movers and shakers*: to formulate, implement and influence policy to ensure that the adverse effects of climate change are regulated and that policies have continuity and overcome any inertia. This group includes the following, among others:

1. Those who make or influence policy in the African Union including the director general of health and food safety, climate in environment research and innovation.
2. Those who make or influence policy at the African member state level.
3. Other opinion leaders at the African regional level, for example WHO-AFRO.
4. Intergovernmental and other bodies operating at the global level, particularly those involved in progressing SDGs.

*Members of academies and educational institutions*: to sensitise and bring the agenda of climate change into public debates and to build capacity in producing climate scientists in Africa. These include the following, among others:

1. NASAC and the academies of science and medicine in the African region and worldwide.
2. Others in the scientific community, including individual researchers and research funders.
3. Through our member academies to the lay public and public health authorities.

*Health Professionals*: to be aware of the burden of climate-sensitive diseases and to recognise and manage the disease burden as well influence the behaviour of communities in adopting behaviour to reduce emissions of greenhouse gases and live a healthy life.

# AUTHOR QUERY FORM

Dear Author,

During the preparation of your manuscript for publication, the questions listed below have arisen. Please attend to these matters and return this form with your proof.

Many thanks for your assistance.

| Query | References Query | Remarks |
|---|---|---|
| 1 | AUTHOR: "Ikäheimo, 2014" has not been included in the Reference List, please supply full publication details. | |
| 2 | AUTHOR: "Müller et al., 2011" has not been included in the Reference List, please supply full publication details. | |
| 3 | AUTHOR: "FAO, 2002" has not been included in the Reference List, please supply full publication details. | |
| 4 | AUTHOR: "Ha, 2018" has not been included in the Reference List, please supply full publication details. | |
| 5 | AUTHOR: "Omazic et al., 2019" has not been included in the Reference List, please supply full publication details. | |
| 6 | AUTHOR: "Jones et al., 2008" has not been included in the Reference List, please supply full publication details. | |
| 7 | AUTHOR: "Mordecai et al., 2019" has not been included in the Reference List, please supply full publication details. | |
| 8 | AUTHOR: "DEA, 2019" has not been included in the Reference List, please supply full publication details. | |
| 9 | AUTHOR: "Barrett and Higgs, 2007" has not been included in the Reference List, please supply full publication details. | |
| 10 | AUTHOR: "Nwaiwu et al., 2021" has not been included in the Reference List, please supply full publication details. | |
| 11 | AUTHOR: "Downing, 2009" has not been included in the Reference List, please supply full publication details. | |
| 12 | AUTHOR: "Cissé et al., 2011" has not been included in the Reference List, please supply full publication details. | |
| 13 | AUTHOR: "Singh et al., 2003" has not been included in the Reference List, please supply full publication details. | |
| 14 | AUTHOR: "Moors et al. 2013" has not been included in the Reference List, please supply full publication details. | |
| 15 | AUTHOR: "D'Souza et al., 2004" has not been included in the Reference List, please supply full publication details. | |

| Query | References Query | Remarks |
|---|---|---|
| 16 | AUTHOR: "Schurman, 2010" has not been included in the Reference List, please supply full publication details. | |
| 17 | AUTHOR: "Cissé et al. 2018" has not been included in the Reference List, please supply full publication details. | |
| 18 | AUTHOR: "de Magny et al., 2007, 2012" has not been included in the Reference List, please supply full publication details. | |
| 19 | AUTHOR: "Mendelsohn and Dawson, 2008" has not been included in the Reference List, please supply full publication details. | |
| 20 | AUTHOR: "Luque Fernández et al., 2009" has not been included in the Reference List, please supply full publication details. | |
| 21 | AUTHOR: "Reyburn et al., 2011" has not been included in the Reference List, please supply full publication details. | |
| 22 | AUTHOR: " Mensah et al., 2015" has not been included in the Reference List, please supply full publication details. | |
| 23 | AUTHOR: "Friel, 2011" has not been included in the Reference List, please supply full publication details. | |
| 24 | AUTHOR: "Mudie et al., 2017" has not been included in the Reference List, please supply full publication details. | |
| 25 | AUTHOR: "USEPA, 2011,d 2014" has not been included in the Reference List, please supply full publication details. | |
| 26 | AUTHOR: "Montavon et al., 2013" has not been included in the Reference List, please supply full publication details. | |
| 27 | AUTHOR: "Hayes et al., 2018" has not been included in the Reference List, please supply full publication details. | |
| 28 | AUTHOR: "World Metrological Organization, 2020" has not been included in the Reference List, please supply full publication details. | |
| 29 | AUTHOR: "Singh, 2003" has not been included in the Reference List, please supply full publication details. | |
| 30 | AUTHOR: "ECA, 2009" has not been included in the Reference List, please supply full publication details. | |
| 31 | AUTHOR: "Dorward et al., 2020" has not been included in the Reference List, please supply full publication details. | |

# 3 Summary of known major health effects of climate change

**Summary of emerging points from chapter 3**

There is a substantial body of evidence linking climate change to the burden of disease globally, but such evidence is scanty in the African continent. It is timely to take prompt and effective actions to mitigate the problem, adapt to it and prevent it from considerably worsening.

There is broad consensus that climate change is driven by human activities resulting in toxic levels of greenhouse gases. Africa is experiencing the globally recognised indicators of climate change including rise in surface temperature, warming and acidification of the oceans, rise in sea levels and melting of ice caps. Climate change results in extreme weather conditions such as drought, floods, storms and fire, imparting many direct health effects and other health conditions. Indirect health effects result from climatic changes affecting water quality, air pollution, land use change and ecological disequilibrium of vector populations. These changes lead to increases in the morbidity and mortality resulting from many climate-sensitive diseases, infectious diseases including vector-borne diseases, respiratory diseases, malnutrition, non-communicable diseases including cardiovascular diseases and mental illness, and other related conditions such as malnutrition, injuries and poisoning. The net result is loss of lives, livelihood, productivity and economic loss.

The main climatic change indicators considered in this chapter are direct ones: namely, rise in temperature, and extreme weather conditions such drought, floods, storms and sea-level rise. Indirectly through changes in human ecosystems, climate change affects environmental ecology and social dynamics, affecting water quality, air pollution, release of allergens, changes in land use associated with agricultural losses, and ecological disequilibrium of vector populations impacting vector-borne diseases. Indirectly, climate change also disrupts the social dynamic because people are demoralised on account of loss of lives and livelihood and resort to forced migration and conflicts in an effort to re-establish their socio-economic status.

The African continent is particularly vulnerable to the health effects of climate change due to its unique topology and climate. This is compounded by the existence of multiple vulnerabilities including social determinants of health such as age, gender and socio-economic status that confer poor adaptive capacity in a health system that is already operating beyond its carrying capacity.

Climate change poses a range of threats to human health and survival that are interconnected in multiple ways. The pathways between exposure and health effects are attributable to multiple direct, indirect or combined exposures. For instance, cardiovascular disease can increase by the direct effect of heat rise, and indirectly by unsustainable farming or crop failure leading to malnutrition and increased risks of non-communicable diseases, or by consumption of salty water because of sea-level rise in coastal areas. So, one single environmental climatic hazard can have multiple health effects. A web of causation links other sectors to the health sector in climate change, although the linkage is not necessarily linear. The effect in one sector leads to spill-over effects in others, and these interlinkages are addressed in the remaining chapters in relation to specific climate hazards.

## 3.1 The underlying basis of climate change

Climate change is undeniably having adverse effects on the health of the African population and these effects must be controlled to protect the human population. Understanding the root causes and pathways of climate change enables us to institute control measures at each step. Climate change results from global warming due to excess greenhouse gases (GHGs) released by collective aggregate human activities such as burning of fossil fuel, intensive farming, urbanisation and the use of non-renewable energy (Solomon, 2007). The main drivers of climate change are population growth and urbanisation. The release of GHGs changes the environment, resulting in climate change that can be measured by local indicators, namely temperature rise (resulting, for example, in the melting of ice caps in the Kilimanjaro mountains), urban heat islands, rainfall, humidity, wind speed, sea-level rise and ocean warming in Small Island Developing States (SIDS), causing costal erosion and loss of biodiversity. The changes in local climatic conditions alter the environment and put vulnerable populations at increased risks for exposure to heat, air and chemical pollutants, storms and extreme weather, food shortage problems, altered water quality, environmental degradation, disease vectors and coastal flooding. As a result, exposed populations manifest various health effects as elaborated in this chapter.

On the basis of the pathway of climate change and health effects outlined above, one can take corrective actions at each step: for example, national policy for population control and reducing non-renewal energy sources in agriculture, transport and energy sectors, urban planning and local pollution control can be used to mitigate the demand for non-renewal energy. Environmental monitoring of climatic hazards and public health incorporating early-warning systems can be used to minimise exposure of vulnerable populations, while adoption of early-warning systems (EWARS) can be used to reduce the health effects of climatic hazards through empowering health-care personnel to recognise and treat the effects of climate-sensitive diseases. These actions are elaborated in this chapter and chapter 4.

## 3.2 The health effects of climate change

Compared with the rest of the world, the African continent has the highest burden of mortality due to climate change (WHO, 2002). As illustrated in Figure 3.1, the WHO estimated that between 80 and 120 climate-related deaths occur per 1 million people every year in Africa. Various subsequent studies or projections have corroborated the staggering number of deaths, illnesses or injuries due to climate change.

### 3.2.1 How exposure to climate change results in adverse health effects

As illustrated in Figure 3.1, the main health conditions are infectious diseases including vector-borne diseases, respiratory diseases, cardiovascular disease including stroke, undernutrition, mental health, injuries, allergies and poisoning. This disease burden may be apportioned to the different ways in which communities are directly or indirectly exposed to the climatic hazards. Basically these exposures are from (1) the direct impacts of climate changes associated with exposure to extreme weather conditions such as heatwaves, drought, storms, flash floods and rising sea levels; (2) the indirect impacts of climate change can be due to alteration of our ecosystem, affecting our water and air quality, or causing disequilibrium of vectors and vector-borne diseases, as well changing agricultural patterns; and (3) indirectly climate change leads to forced migration when populations are demoralised due loss of lives, livelihoods and properties.

Since the exposure pathways are many, the exposed population may invariably experience the direct and indirect impacts simultaneously, as illustrated in Figure 3.2. Therefore, climate change poses a range of threats to human health and survival that are interconnected in multiple interacting ways. One single environmental climatic hazard can have multiple health effects: for example, cardiovascular disease can increase by the direct effect of heat rise, and indirectly by unsustainable farming or crop failure leading to malnutrition, or consumption of salty water leading to increased risk of non-communicable diseases (NCDs). Similarly, a web of causation links other sectors to the

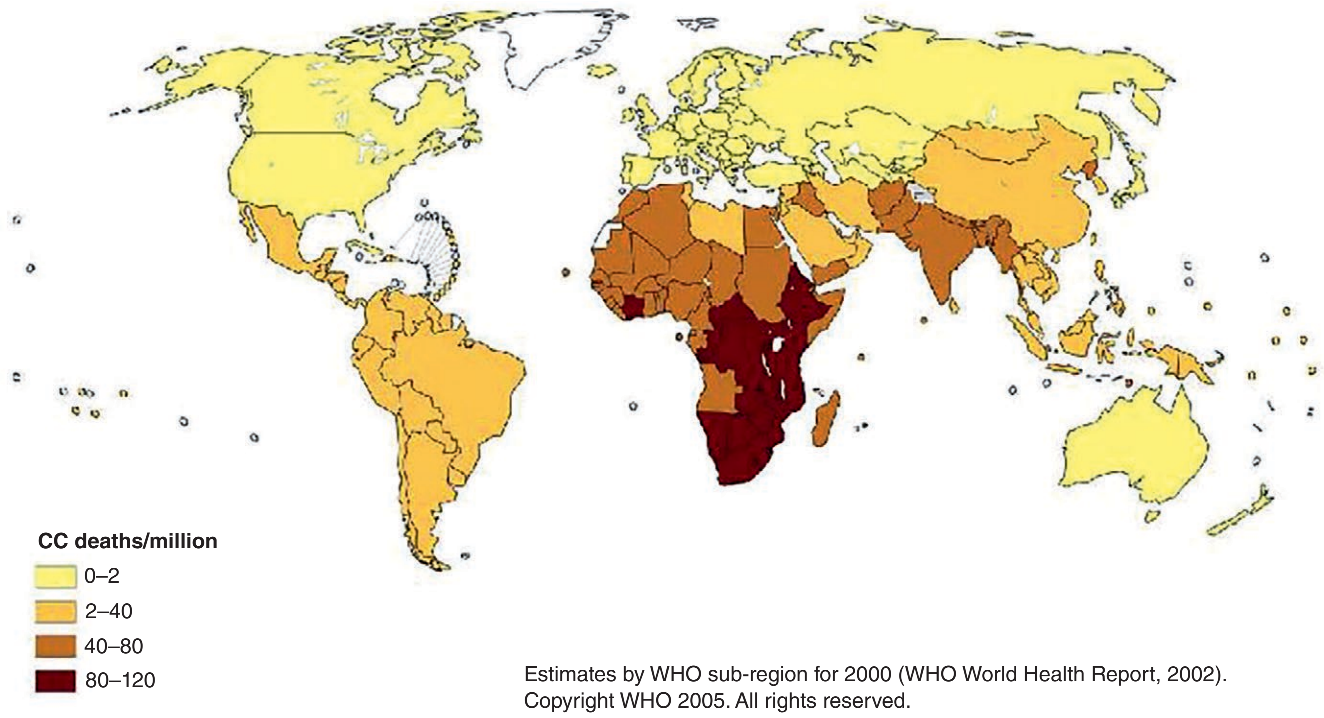



*Figure 3.1 Highest disease burden due to climate change in Africa.*



health sector in climate change, although the linkage is not necessarily linear. The effect in one sector leads to spill-over effects in others. This theme resonates in vector-borne diseases, air pollution and food-borne diseases among others. These interlinkages are further elaborated under specific climatic hazards in the ensuing sections of this chapter.

## 3.3 Direct health effects due to climate change

The primary consequences of climate change are relatively direct and usually caused by the frequency and intensity of weather extremes. This section examines the direct primary health consequences of climate associated with exposure to the physical hazards of heatwaves and extreme weather events including storms, forest fire, floods and drought.

### 3.3.1 Rise in temperature

*Health effects*. Temperature rise results in heatwaves. It directly and indirectly affects human lives and livelihoods: it contributes to heat stress, heatstroke, hyperthermia, and cardiovascular, respiratory and cerebrovascular disease, particularly among elderly people, people with pre-existing diseases and people living in poverty. High temperature also raises the levels of tropospheric ozone and other pollutants in the air which exacerbates cardiovascular and respiratory diseases. People vulnerable to heat-related complications include children, the elderly, people with outdoor occupations and women. Heat exposure also holds particular dangers for pregnant women and the developing foetus, a pressing concern given the already high levels of maternal and infant mortality in the African continent (Chersich *et al*., 2018). Temperature rise also leads to reduced output, especially for outdoor workers, and loss of productivity (Kjellstrom, 2014).

*Current situation in Africa*. The most marked illustration of heat rise in Africa is the melting of icecaps in the Kilimanjaro mountains, as elaborated in Case Study 1 in this chapter. In the past 130 years, the world has warmed by approximately 0.85 °C. Each of the past three decades has been successively warmer than any preceding decade since 1850 (Solomon,

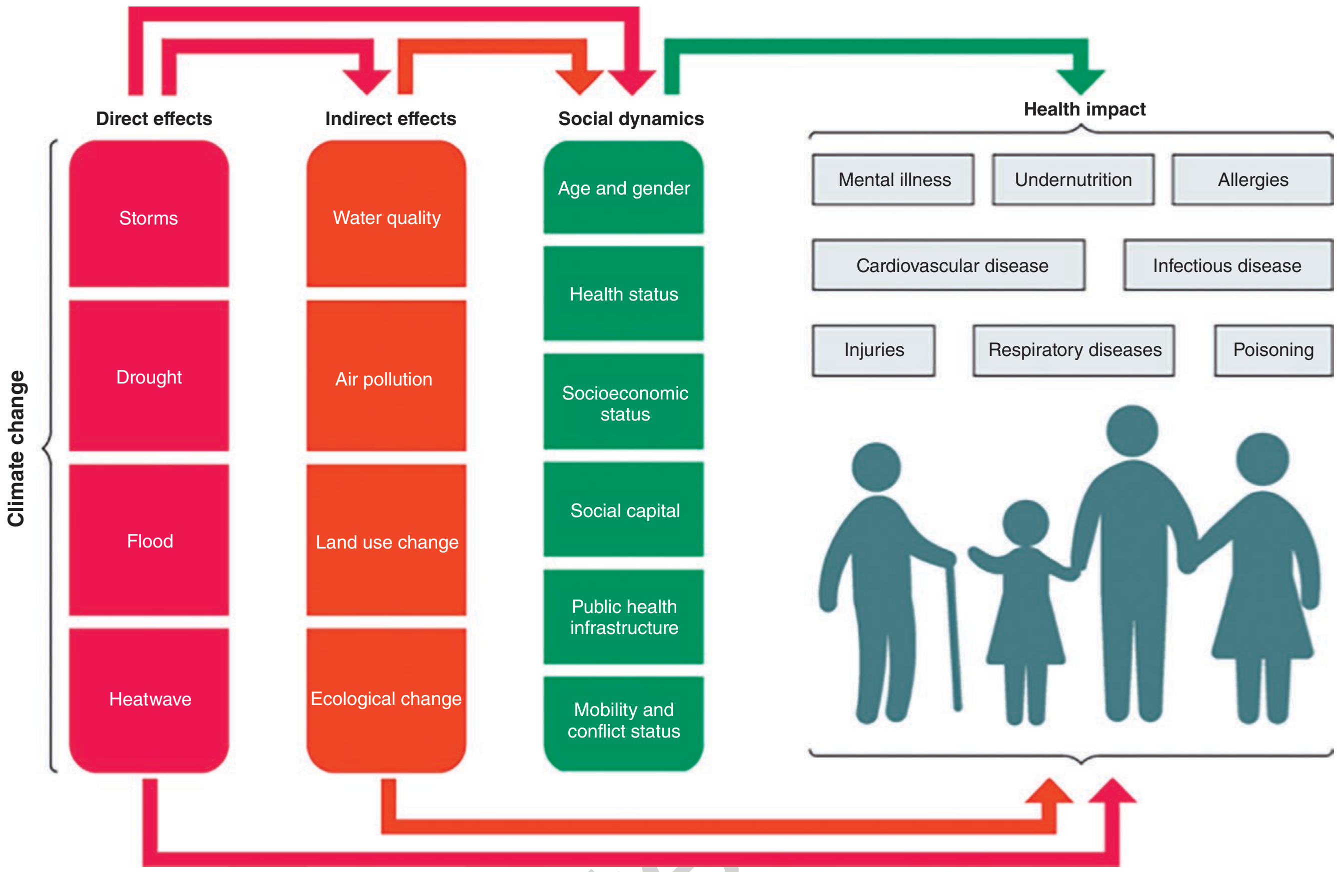



*Figure 3.2 Exposure pathways and health effects of climate change*[1].



2007; IPCC 2021, 2022). Decadal analyses of temperatures strongly point to an increased warming trend across the continent over the past 50–100 years, and this trend will continue to increase if unmitigated (IPCC, 2014a; UNFCCC AR6, 2020). For example, in the Conformal Cubic Atmospheric Model (CCAM), a statistical model that can simulate climate and weather at fine resolutions over a range of topography (Engelbrecht *et al.*, 2015; Garland *et al.*, 2015) (Figure 3.3), the mean annual temperature rise over Africa, relative to the late 20th century mean annual temperature, is likely to exceed 2 °C by the end of this century in the Special Report on Emissions Scenarios (SRES) A1B and A2.

*Mortality due to heat rise*. Climate change is associated with a significant increase in heat-related mortality: a rise of 1 °C may be associated with a mortality rate of between 1% and 2% (Ikäheimo, 2014). Mortality due to heatwaves has been studied in Europe. For example, during the heatwave in the summer of 2003, more than 70,000 excess deaths were recorded (Le Tertre *et al.*, 2005). Similar observations have been made in North America. However, such comparable data are sparse for Africa (McMichael *et al.*, 2004, 2006) and much of the evidence is derived from case studies or research projects.

Although country-specific heat-related mortality data are not available for all countries in Africa, a study from South Africa, using national mortality and temperature data for each district over 17 years, found that temperature-related mortality accounted for 3.4% of deaths (Scovronick *et al.*, 2018). Those at the extremes of age

[1] Watts *et al.* (2017).

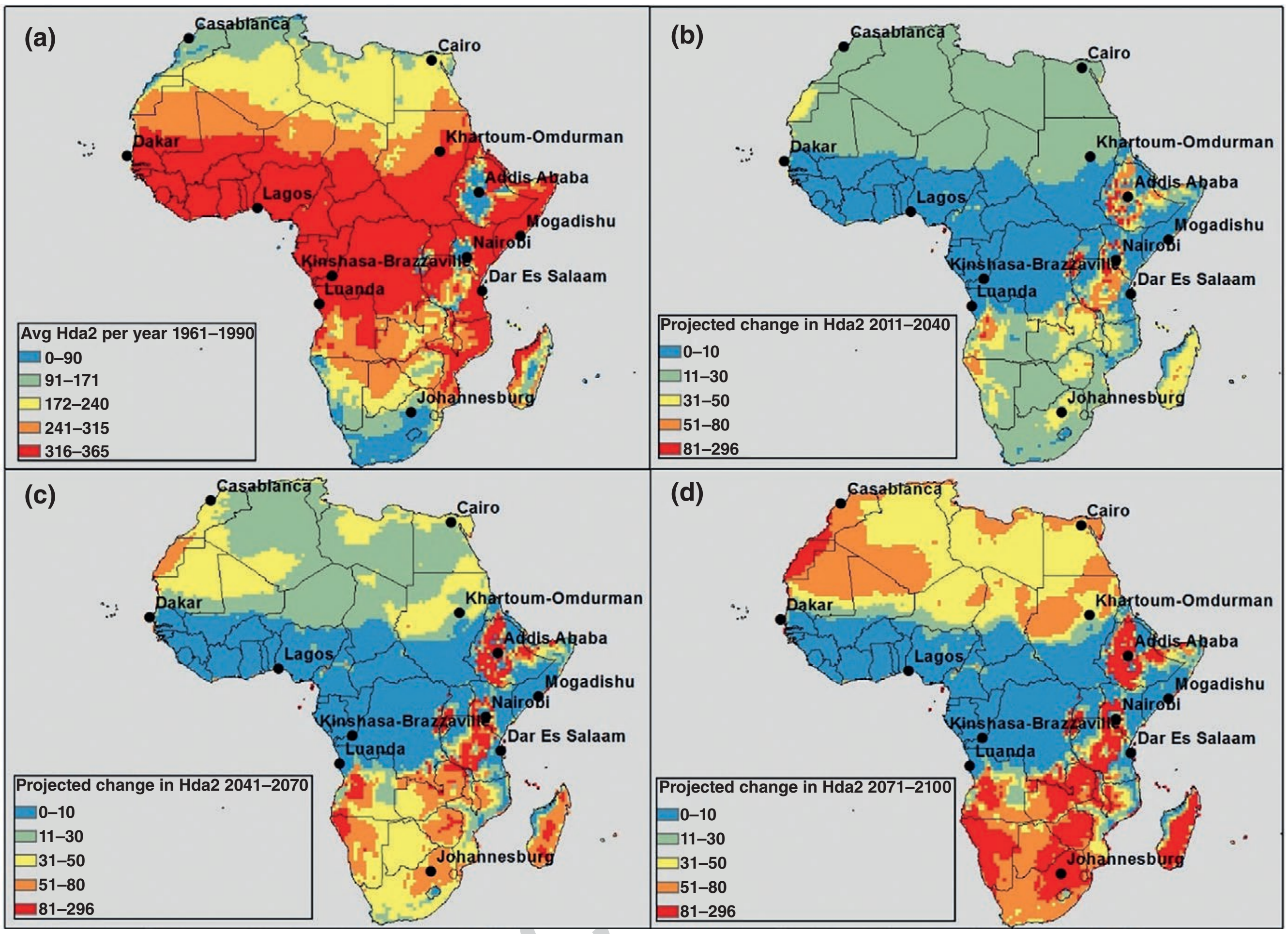



*Figure 3.3 Projected model for heat rise in Africa[2]. (a) Average number of hot days (Hda), where Hda2 represents the number of days where the maximum apparent temperature was ≥27 °C per year in the present climate. (b) Projected change in the average number of Hda2 per year in 2011–2040 compared with 1961–1990. (c) Projected change in the average number of Hda2 per year in 2041–2070 compared with 1961–1990. (d) Projected change in the average number of Hda2 per year in 2071–2100 compared with 1961–1990.*

were most vulnerable, given their reduced thermoregulatory ability, as well as more limited mobility and resources to adjust to extreme temperatures. A study from Cape Town, Durban and Johannesburg calculated that for every 1 °C rise, overall mortality escalates by 1% and by 2% in those aged above 65 years. Similarly, other time-series studies from Burkina Faso, Ghana and Nairobi also support an association between rising temperature and daily mortality rate, especially for the under-5 age group (Azongo *et al*., 2012; Diboulo *et al*., 2012; Egondi *et al*., 2012). Since many parts of Africa lie in the equatorial and desertic zones and are projected to have temperature rise, the actual number of mortalities is likely to be high but underreported.

*Heat-related mortality projection for Africa*. An increase in future heat-related mortality is seen as one of the most likely impacts of future anthropogenic climate change (Smith *et al*., 2014). An increase in health effects is projected both from increases in average seasonal temperatures (Huang *et al*., 2011) and from increases in the frequency and intensity of heatwave events (IPCC, 2012).

[2] Garland *et al.* (2015).

**Case Study 1  Melting of ice on the Kilimanjaro mountains**

Melting of ice on eastern Africa's mountains: the melting of ice caps on Kilimanjaro mountain peaks in equatorial East Africa, one of the few places in the world where ice and snow can be found at the Equator, illustrates the impacts of rising temperature on environmental quality.

Mount Kilimanjaro has always been snow-capped and a source of many rivers which flow from its ice-capped peaks. In 1990 ice could be seen at heights as low as 2700 metres above sea level on the mountain. The ice melted gradually: between 1976 and 2000, 49% of the ice cap had melted; between 2000 and 2009, a layer of ice between 6 feet and 17 feet had melted from Kibo peak; and 84% of the ice cap had melted by 2012. As of 2020, there was very little ice on Kibo peak at a height of 5685 metres above sea level, while Mawenzi peak has lost all its ice. Ice caps on Mount Kenya have shrunk by 60% since 1963 (Figure 3.4). Mount Meru in Tanzania completely lost its ice cap in 1980. These observations are consistent with the vulnerability of these mountains to the consequences of global warming and climate change (Nkemdirim, 2003).

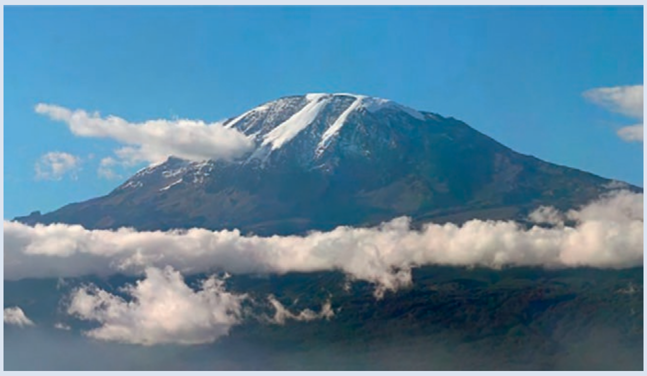


*Figure 3.4  Mount Kilimanjaro, showing the receded ice cap on Kibo peak at 5685 metres.*

The consequences of ice loss on Mount Kilimanjaro are reflected in regime change in many rivers which used to flow from the mountain. These have dried up, making the area semi-arid due to reduced stream flow and negatively affecting the food security of the local people. It is estimated that Mount Kilimanjaro's glaciers will be melted and gone by 2030 (Kaser *et al*., 2004).

*Lessons learnt*. This Case Study clearly demonstrates that there is no return beyond the tipping point; rising temperature is melting the icecaps that cannot be replenished. It also illustrates how the impacts of climate change are interrelated: rising temperature melted the ice caps, changing the topology of the land and affecting the lives and livelihoods of the local communities. It calls for mitigation measures to halt heat rise on the continent and support for affected communities in adapting to the health and economic challenges of climate change.

A quantitative risk assessment model by WHO for a scenario with no adaptation measures forecast an additional 7,387 heat-related deaths by the year 2030 for sub-Saharan Africa, compared with 92,207 for the global figure (Hales *et al*., 2014; WHO, 2014). This increase will not be evenly distributed: countries within hot zones such as sub-Saharan eastern and western zones are projected to have higher mortality than cooler regions such as Northern Africa, reflecting the physical and social vulnerability of the land and the population (WHO, 2014). It must be pointed out that there is difficulty in predicting the effects of changes in the frequency and intensity of heatwaves on mortality rates in high-temperature regions such as in Africa because of this lack of data about mortality in these regions. Impacts of heatwaves differ from the more insidious, but no less harmful, rises in heat with increasing heat-related symptoms.

*Other heat-related impacts*. As temperatures rise, health risks from occupational exposure to heat may increase from 'low risk' to 'moderate or high risk', especially in the mining, agriculture and outdoor service sectors (Kjellstrom *et al*., 2014). Outdoor workers in Upington, one of the hottest parts of South Africa, reported frequent heat-related effects, including sunburn, sleeplessness, exhaustion and reduced productivity (Mathee *et al*., 2010; Chersich *et al*., 2018).

Impacts of heat in the domestic environment are also an important consideration. Although such impacts have not been documented for the whole of Africa, data are available for South Africa. Low-cost government-built housing in

South Africa and informal settlement houses (mostly made of sheets of corrugated iron, bricks, wood and plastic) are poorly insulated against heat and cold. During hot weather, these structures may be 4–6 °C warmer than outdoor temperatures, and cooler during cold spells by the same magnitude (Kapwata *et al*., 2018). Replacing informal settlement housing with formal brick and cement housing could reduce heat-related mortality by as much as a half. Similarly, many school classrooms in the country are constructed of prefabricated asbestos sheeting with corrugated iron roofing, are overcrowded and lack ceiling fans. Temperatures in these structures often exceed 30 °C and heat–health-related symptoms are commonplace (Bidassey-Manilal *et al*., 2016). Equally concerning is the evidence that temperatures in many waiting rooms in public-sector health facilities are dangerously high. A study of eight rural clinics found that the temperature in these clinics was as much as 4 °C higher than outdoors, reaching temperature ranges associated with heat–health impact warning categories of 'caution' and 'extreme caution' (Caradee *et al*., 2017). In addition, already vulnerable inner-city areas constitute urban 'heat islands', where temperatures can exceed that of suburban areas by several degrees (Chersich *et al*., 2018). Case Study 3 from the Côte d'Ivoire shows that creating green spaces in urban planning reduces the direct impact of heat.

*Economic cost of heat.* The direct damage costs to health (i.e. excluding costs in health-determining sectors such as agriculture and water and sanitation) are estimated to be between US$2 billion and US$4billion per year by 2030. Areas with weak health infrastructure – mostly in low- and middle-income countries – will be the least able to cope without assistance to prepare and respond (Hales *et al*., 2014).

##### *3.3.1.1 Recommendations for heat-related disorders*

1. Institutional policy
   (a) Incorporate green spaces in urban planning to reduce heat islands.
2. Health adaptation
   (a) Institute EWARS to anticipate the necessary surge capacity for heatwaves.
   (b) Strengthen the health system to cope with surges in heat-related illnesses.
   (c) Configure work schedules to minimise direct exposure to heat.
3. Mitigation
   (a) Phase in green technologies in sectors to reduce GHG emissions.
4. Strengthening evidence base
   (a) Undertake country-level studies to establish dose–response relationships for health.

### 3.3.2 Hydrological disasters: storms, heavy precipitation and floods

With increasing global surface temperatures and the possibility of more droughts, more water vapour is evaporated into the atmosphere where it becomes fuel for more powerful storms to develop. Storms and floods are two hydrological disasters of climate change that are addressed jointly in this section because a storm usually brings lots of rainfall that gives rise to floods. Drought is also a hydrological disaster, but it is considered in a separate section since it has some different features.

### 3.3.3 Interlinkage of storms, precipitation and floods

A storm is an extreme weather condition with very strong wind, heavy rain and often thunder and lightning. The most common type of storm in Africa is a tropical cyclone, characterised by violent and destructive winds of more than 116 km/hour sustained wind speed, torrential rain, coastal storm surges and coastal flooding as experienced by countries bordering the southeast and southwest of the Indian Ocean (WMO, 2020). In Case Study 2, we document the powerful and devastating effects of a deadly storm named Idai.

Flood is triggered by a severe storm depositing large amounts of precipitation over a short time and small region. Generally, 50 mm of water in 1 hour is the threshold for a torrential storm to trigger immediate or subsequent floods. Flood is usually considered a secondary event after a cyclone. But floods can also occur independently of a storm due to severe precipitation. In Case Study 3, we document the vulnerabilities to floods and heat in Côte d'Ivoire to illustrate the need for intersectoral collaboration in urban planning.

**Case Study 2 Devastating effects of Cyclone Idai in Mozambique**

Cyclone Idai, which hit Mozambique in March 2019, illustrates to what extent the tropical cyclones linked to climate change are changing their paths inwards on the African continent and causing incalculable damage. This tropical depression turned into a tropical cyclone with wind speeds of 165 km/h and wind gusts reaching 230 km/h. It hit the Beira region of Mozambique and the eastern part of Zimbabwe, causing torrential rain and storm surges exceeding 10 metres. Cyclone Idai is the deadliest storm recorded in Africa, killing 602 people, injuring around 1,600, affecting 1.8 million and causing economic loss of around US$773 million (OCHA, 2019). It also resulted in 6,000 cases of cholera which were aggravated by the cyclone event (Centre for Research on the Epidemiology of Disasters (CRED Crunch), 2019; World Metrological Organization, 2020;). This region of Africa seems to be prone to tropical cyclones making inward encroachments from what used to be a primarily coastal phenomenon. 28

Lessons learnt from this case study. This cyclone illustrates that extreme weather conditions, besides causing loss of life and property, can lead to cascading by affecting the water system through contamination by cholera. It calls for health adaptation to manage infectious disease outbreaks ensuing from floods and cyclones. There is also a need for a cross-sector plan to ensure mitigation measures in the form of an early-warning system and collaboration of regional governments on tailored disaster preparedness, disaster reduction and disaster management strategies which can minimise the devastating impacts caused by hydro-meteorological disasters.

**Case Study 3 Vulnerability to flood and heat in Côte d'Ivoire**

This case study is based on articles published by Kablan *et al*. (2017) and Dongo *et al*. (2018). It seeks to establish the vulnerability of residents to heat and flood. The study was conducted in Cocody (Figure 3.5), in one of the 10 districts of eastern Abidjan in Côte d'Ivoire. This district was selected because it is one of the wealthiest in Abidjan with a large amount of land for urban expansion, with the view that the results could be relevant to urban management and planning.

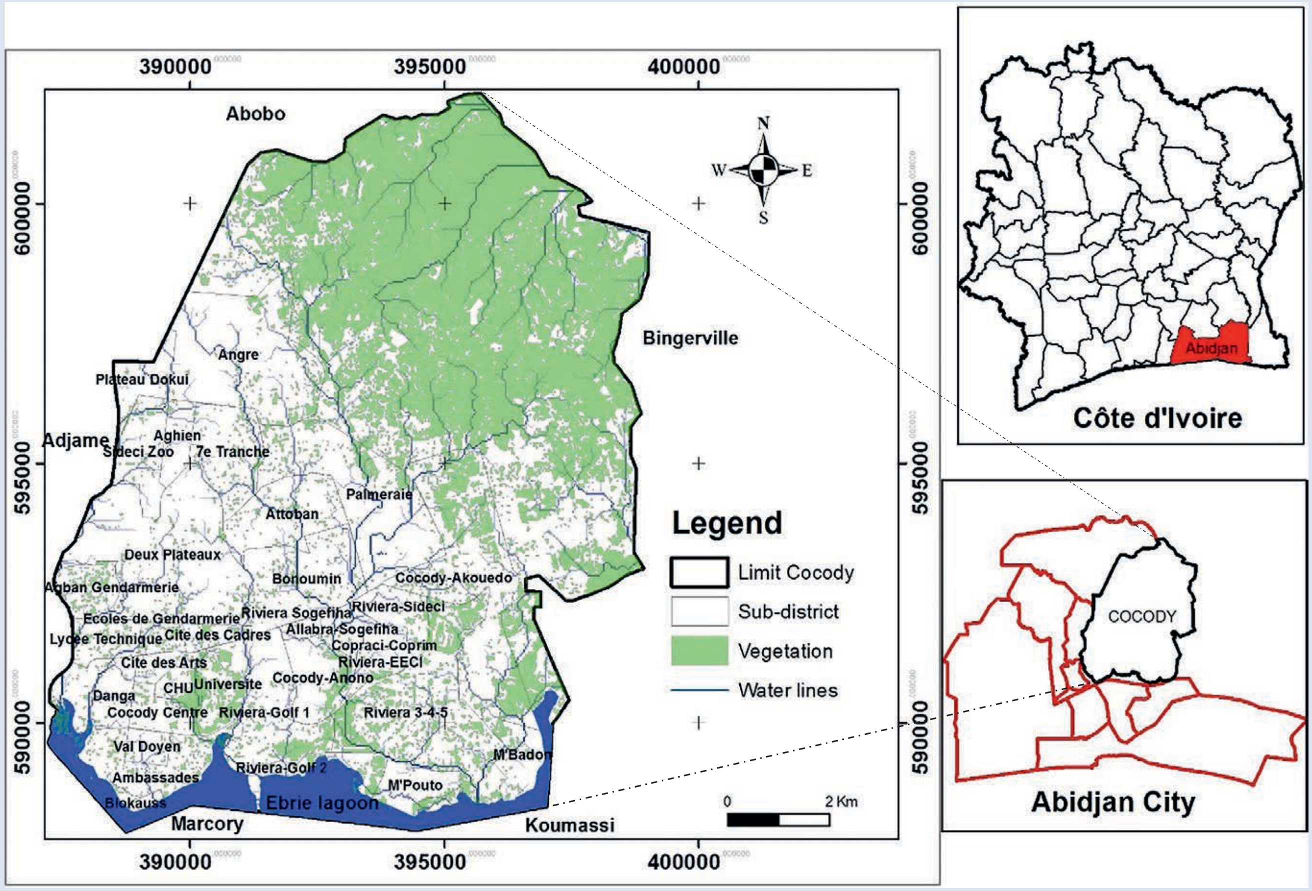



*Figure 3.5 Study area in Cocody.*

The MOVE framework (Methods for the Improvement of Vulnerability Assessment in Europe) was used. Briefly, this uses three parameters: vulnerability in terms of exposure; susceptibility/fragility; and lack of resilience (Birkmann *et al.*, 2013). A vulnerability index of a given neighbourhood is then calculated on the basis of these three parameters, as follows:

- Exposure (E): describes the extent to which a unit of assessment falls within the geographical range of a hazard event; for example, population density and flooded area per district, spatial variation of temperature.
- Susceptibility (S): describes the predisposition of elements at risk (social and ecological) to suffer harm; for example, percentage of women, children and the elderly.
- Lack of resilience (LoR): describes the limitations in access to and mobilisation of resources of the socio-ecological system and its incapacity to respond by absorbing the impact; for example, literacy rate, unemployment rate, green space surface per district area.

*Results of vulnerability to flood and heat*. The vulnerability index for flood is shown in Figure 4.7a. It can be observed that some low social standing sub-districts with 'lack of resilience' seem less vulnerable than some so-called prestigious sub-districts. This situation can be explained by the fact that vulnerability is strongly correlated with susceptibility and exposure and not with the lack of resilience. When looking at the study done by Depietri *et al*. (2013), one can realise that some sub-districts with high 'lack of vulnerability' came out with low vulnerability. This
29 result could be explained by the aggregation process (Singh, 2003). It means also that although an area may be highly exposed to a hazard, it can be less vulnerable if it has adequate means to adapt to the phenomenon. Vulnerability is therefore not a matter only of exposure, but rather it is a combination of exposure with local socio-economic factors (Halounova and Holubec, 2014).

**(a) vulnerability to flood** **(b) vulnerability to heat**

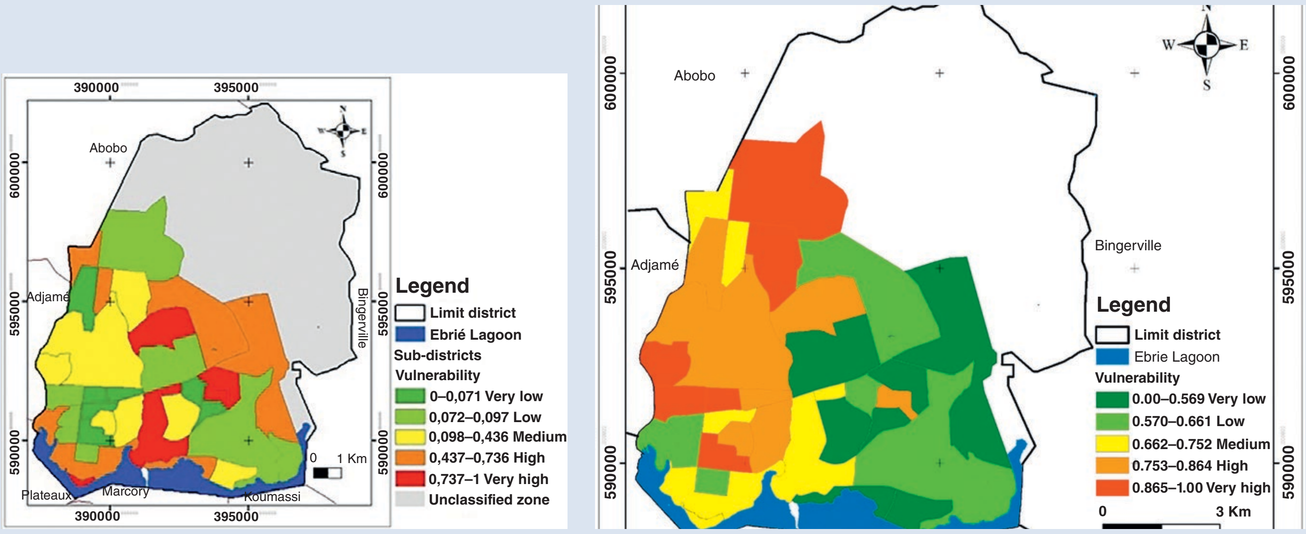



*Figure 3.6 Vulnerability to (a) flood and (b) heat in Cocody.*

*Results of vulnerability to heat*. As illustrated in Figure 4.7b, overall vulnerability to the effects of heat was highest in most low-standard neighbourhoods, where most heat-sensitive people (children) were registered. In addition, the percentage of insured people in these areas was also low, and most residents lacked considerable and adequate urban green space that could have helped them acclimatise and reduce the exposure of the more fragile strata. Thus, apart from the visible impacts (heat-related diseases) on populations, human insecurity related to the effects of extreme temperatures violates some of the most basic principles of social justice as mentioned in the first principle of the 1972 Declaration of the UN conference on the environment held in Stockholm (Sotoudehnia and Comber, 2010). Therefore, proper and adequate distribution of green spaces in areas that are less resilient and more exposed to extreme heat conditions could be a way to reduce social injustice and promote human security (Wolch *et al.*, 2014).

Moreover, green space can be a tool for disaster risk reduction, representing a safe venue for emergency services such as provision of relief supplies as well as for setting up a security command centre and medical aid stations (Liu *et al.*, 2013).

*Lessons learnt from this study*. The results of our vulnerability assessment suggest that, to effectively tackle the vulnerability of Cocody district to extreme heat conditions, collaboration among local city authorities in charge of urban planning and environmental management is needed to implement strategies that will improve the socio-environmental conditions of the city for the well-being of the residents. The main greening strategies should consider the spatial distribution of susceptible groups across the district. A more active use of population demographics and background characteristics for district planning could be helpful when planning and managing green space in urban areas. Results further indicate that green spaces, density and age class are important factors that need to be considered for tackling vulnerability to heat. City planners should, therefore, take the distance to green space into consideration, especially for new residential areas, areas with many residents and areas where distance is more likely to be a limiting factor. Also, private vegetation planting at the household level should be encouraged (Flanagan *et al.*, 2011; Liu *et al.*, 2013; Rufat *et al.*, 2015). For vulnerability to flood, the results also highlight that designing a proper management strategy to tackle flooding in urban areas requires integrated approaches which consider a broader set of local indicators that consider the social, physical and ecological dimensions of vulnerability.

*Current situation*. According to the International Disaster Database, University of Leuven, there were 276 storm events in Africa between 1900 and 20 June 2020 affecting more than 23 million people. Of these, 139 were tropical cyclones and 83 were convective storms. The most affected regions in terms of the number of recorded cyclones were Eastern Africa with 163, Southern Africa with 40 and Western Africa with 34 storm events. Considering only tropical cyclone events, Eastern Africa was the most affected region, experiencing 129 tropical cyclones followed by Western Africa with 5 and Southern Africa with 3 tropical cyclone events (EM-DAT, 2020).

**Table 3.1 Projected annual mortality ranges due to cyclones and coastal floods**[3]

| Region | 2030 | 2050 | 2080 |
|---|---|---|---|
| Sub-Saharan Africa, central | 30–100 | 30–100 | 30–100 |
| Sub-Saharan Africa, eastern | 1,000–3,000 | 3,000–10,000 | 3,000–10,000 |
| Sub-Saharan Africa, southern | 0–3 | 0–3 | 0–3 |
| Sub-Saharan Africa, western | 1,000–3,000 | 1,000–3,000 | 3,000–10,000 |

Note that Northern Africa is included in the Middle East according to the WHO classification of regions (North Africa and Middle East).

*Linkage between climate change and health impacts*. In Africa, 13.48 million people were affected and 3686 died because of 172 storm events that occurred in the period 2000–2019. The health impacts of storms can be direct such as drowning but it is the secondary events such as floods, landslides and tornadoes that have more consequence. These health consequences can be mortality, morbidity and injury. Mortality could be due to drowning, electrocution, infrastructure collapse or water-borne diseases such as cholera. Morbidity is due to infectious diseases, vector-borne diseases or mental health such as trauma. Injuries result from contact with hidden sharp materials, and animal bites such as snakes and reptiles. In addition to health impacts, storms can result in disruption to health services because of bridge collapses, broken roads and damaged health infrastructures. Disruption to basic supplies such as food, drinking water and electricity lines mostly escalates in the aftermath of storm events (Shultz *et al*., 2005).

Flooding leads to crop failure resulting in food insecurity, triggering malnutrition. Flooding also affects the ecosystem by contaminating water and the food we consume, leading to a rise in water- and food-borne disease, as elaborated in section 3.4.4. Furthermore, flood-induced crop failure, by causing malnutrition, puts the population at an increased risk of non-communicable diseases, especially diabetes and cardiovascular diseases (see section 3.4.5).

*Projection*. The projection in the literature is for the mortality caused by coastal floods (secondary event) resulting from tropical cyclones and storm surges rather than storms in general to increase. Every year 120 million people around the globe are affected by coastal floods caused by tropical cyclones and storm surges resulting in average annual deaths of 12,000. Unfortunately, there is no projection for the number of people who will be affected in Africa by coastal floods but only the mortality projections. Table 3.1 shows this projection for different parts of Africa (Lloyd *et al*., 2014). It is clear that tropical storms and their associated floods will increase in the years ahead, driven by climate change. This increase will not be uniform across Africa; rather, more pronounced is eastern and western sub-Saharan Africa where between 1,000 and 3,000 deaths might be expected in 2030. South and Central Africa are expected to have marginal increases.

Because of its tropical location, poverty, weak institutions, conflicts and low capacity to

[3] Adapted from Lloyd, S *et al*. (2014).

cope with the effects of temperature rise at 1.5 °C by 2030, amplified to 2 °C by 2090, sub-Saharan Africa, especially west, central and southeastern regions, will experience frequent intense climate extremes in the form of floods (IPCC, 2021).

### 3.3.4 Drought

Drought is a recurrent climate phenomenon characterised by prolonged dry weather and lack of precipitation. It is a slow-onset disaster that can occur anywhere in the world, resulting in water shortage and moisture deficiency. The causes of droughts are essentially natural, but climate change increases the severity because of heat rise causing excess vapourisation frequency, duration and spatial extent.

*Current situation in Africa*. The vulnerability of Africa to the climatic hazard of drought is linked to climate change and compounded by the following vulnerabilities. (1) Sixty per cent of Africa's land mass is made up of dry lands, 38% of which is desert (Sahara, Kalahari and Namib). The Sahara desert, whose area is 9 million $km^2$, covers large parts of the Sahel region (Algeria, Chad, Egypt, Libya, Mali, Mauritania, Morocco, Niger, Sudan and Tunisia) and accounts for 31% of Africa's land area. (2) Fifty per cent of Africa's population live in the arid, semi-arid, dry sub-humid and desert lands. (3) The location within the arid tropics which are normally moisture constrained and highly dependent on rain-fed agriculture. (4) Exposure to damaging climate risks including extreme droughts, floods and storms. (5) Low adaptive capacity caused by high rates of poverty, and financial and technological constraints. The assessment report of the IPCC confirmed that 'Africa is the most vulnerable continent to climate variability and change particularly droughts' (IPCC 2007). It is the driest continent with 60% of the land area frequently receiving below normal rainfall (EM-DAT, 2020) and consequently 60% of the continent suffers from all the categories of drought (meteorological, hydrological, agricultural and economic).

Drought can have both direct and indirect consequences resulting in crop failure, food shortages, famine, malnutrition, deaths of humans and livestock, land degradation, aridity and desertification (Parry, 1988; WHO 2003). The frequent droughts have caused devastating impacts on health, water and agriculture, resulting in the collapse of rain-fed agriculture, reduced grain yields, diminished food security, livestock mortality, and decreases in the water volumes of major rivers which are used for irrigation such as the Niger, Senegal, Nile, Zambia, Zambezi, Volta, Athi and Tana rivers (Orindi, 2005). Droughts have negatively affected the pastoral farming activities of the Karayu in Ethiopia, Tueregs in the Sahel, the Masaai in Kenya and Tanzania and the Karamojong of Uganda (Tear Fund, 2010).

Droughts in Africa have become more frequent, intense and widespread during the past 50 years. For example, the extreme droughts of 1972–1973, 1983–1984 and 1991–1992 affected the whole continent whereas others affected specific regions as follows: the 1999–2002 drought in northwest Africa; the 1970s and 1980s droughts in Western Africa (Sahel); the 2001–2003 drought in Southern and Southeastern Africa; and the 2010–2011 drought in Eastern Africa (EM-DAT, 2020). Between July 2011 and mid-2012, a severe drought termed by the UN as 'the worst in 60 years' affected the entire East African region and caused a severe food crisis across Somalia, Djibouti, Ethiopia and Kenya which threatened the livelihoods of 9.5 million people.

*Effects of drought on health*. Detailed analysis by the Center for Disease Control and Prevention (CDC, 2018) lists the main health effects of drought in Africa as follows: (1) agriculture and food security; (2) water scarcity; (3) dust, smoke and heat related. Water-related effects are categorised as (1), those 'transmitted by water/water-borne' diseases, which are transmitted through faecal–oral route, including different types of diarrhoea and gastroenteritis caused by the bacterium *Escherichia coli*; (2) 'water-based'

**Case Study 4 Tanzania: drought impacts on human health**

Tanzania, one of the east African nations, is expected to experience average temperature increases between 1.9 and 3.6°C and a sea-level rise between 65 centimetres and 1 metre. Furthermore, rainfall is expected to decrease in the dry season and to increase during the rainy season, leading to a growing risk of floods, water shortages and related conflicts. The Economics of Climate Adaptation Working Group conducted a case study focusing on the spread of cholera and other infectious diseases exacerbated by the shortage of potable water as a result of drought. This study correlated historical rainfall data with incidence cases of cholera and most common infectious diseases as well as crop supply and demand imbalances as an indicator of malnutrition. The study identified drought-related health impacts as malnutrition, trachoma (an infectious eye disease that causes blindness), dysentery, cholera and diarrhoea (ECA, 2009) and concluded 'that by 2030, under the moderate climate 30
change scenario, a 10 percent decrease in average rainfall was projected to cause a 60 percent increase in the proportion of the population under food stress, and significant increases in the number of cases of cholera and dysentery. Trachoma cases were estimated to potentially double in number. The high climate change scenario would worsen this impact'.

*Lessons learnt*. The east African region is the poorest in the world and thus the most vulnerable to climate change and its impacts. The vulnerability of Tanzania to the health impacts of drought is due to its exposure to climate change and the low adaptive capacity of the population. It demonstrates that there are tipping points beyond which climate-sensitive infectious disease will pose a threat to development. It highlights the need for mitigation and adaptive measures to avert mortalities and morbidities due to drought.

diseases transmitted by pathogenic species that have life cycles linked to water such as schistosomiasis; (3), 'water-related' diseases, in which the vector has a cycle involving water, such as cholera (the highest case fatality rates of cholera occur in sub-Saharan Africa), dengue, West Nile virus and malaria (with a high prevalence in Eastern Africa); (4) 'water-washed' diseases, in which a water shortage affects personal hygiene resulting in infectious diseases being contracted such as trachoma and parasites such as scabies and lice (very common in sub- Sahara, the Horn of Africa and South Asia) where inadequate sanitation and scarcity of safe water access is associated with an increased occurrence of diarrhoeal diseases in children. Food-related diseases include complex malnutrition and deaths due to lack of food, famine, marasmus and kwashiorkor in children, with over 15 million children under 5 years having acute malnutrition in West and Central Africa by July 2020 (WHO, 2016, 2016a, 2017; FAO, 2019). Anxiety and depression due to economic losses, conflicts in times of water scarcity and reduced incomes are common among the pastoralist communities in Africa. Case Study 4 illustrates how historical data can be used correlate outbreaks of cholera, a water-borne disease that is transmitted because of poor sanitation during drought.

The effects of drought on human health vary widely depending on the severity of drought, baseline population vulnerability, existing health conditions and sanitation infrastructure. For example, in China, respiratory diseases are spreading more easily in the most vulnerable groups of the population including children, the elderly and people with chronic or predisposing conditions such as allergic persons and smokers (Bifulco and Ranieri, 2017). In the Mediterranean countries, warmer temperatures and droughts have increased the recurrence of wildfires, exposing large populations to toxic emissions including particulate matter (PM) and other harmful compounds of smoke.

In urban areas, the scarcity of rain causes the exacerbation of acute and chronic respiratory tract disorders (asthma, allergies, bronchitis and pneumonia) due to the accumulation of allergens, fine dusts and industrial pollutants. Studies conducted in California, a region at a high risk of droughts, established a strong correlation between periods of drought and increased mental health problems among inhabitants (Bifulco and Ranieri, 2017).

*Future projection*. Future projection by the General Circulation Model, the Coupled Model Intercomparison Project Phase 5 (CMIP5), shows temperature increases for Africa with the current emissions trajectory (RCP 8.5) will be 1.7 °C by the 2030s, 2.7 °C by the 2050s, and 4.5 °C by the 2080s (Girvetz *et al.*, 2009, 2018). The increases will cause more severe droughts, more aridity, less food production and greater food insecurity across Africa (Müller *et al.*, 2011). The current 2
growing areas of Africa's staple food (maize

and beans) will experience yield reductions of 12–40% by 2050. Climate suitability for most major crops and livestock is projected to shift as the climate warms and becomes more arid, posing serious concern for food security and nutrition. It is projected that by 2080 over 30% of the maize-growing areas and over 60% of the bean-growing areas will shift and grow entirely different crops (Rippke *et al*., 2016). In the case of livestock, increases in temperature and decreases in rainfall could increase the suitability of the main tick vector of East Coast fever across much of Southern Africa by 2050 (EM-DAT, 2020). A possible increase in malnutrition rates, stunted growth and impaired cognitive development has been projected to occur among young children by 2050 (Lindvall *et al*., 2020). Although future precipitation is much more difficult to model (Sillmann *et al*., 2013), over 80% of the climate models agree on decreased precipitation and increased aridity in some parts of northern and Southern Africa by 2050 (Girvetz *et al*., 2018). However, the complex and highly variable nature of many physical mechanisms of weather such as the El Niño–Southern Oscillation (ENSO), sea surface temperature and land–atmosphere feedback adds to the daunting challenge of drought monitoring and forecasting in Africa as there is lack of technical capacity (Masih *et al*., 2014).

#### 3.3.5 Specific recommendations for hydrological disasters

1. Institutional policy
   (a) Forge formal partnerships with regional climate information institutes such as the Drought Monitoring Centre in Nairobi and others to deliver customised climate services to increase resilience and adaptation.
2. Health adaptation
   (a) Institute EWARS to anticipate the necessary surge capacities for storms, flood, droughts and bushfires.
   (b) Strengthen health systems to cope with surges in hydrological- and bushfire-related illness.
   (c) Configure work schedules to minimise direct exposure to heat.
3. Mitigation
   (a) Phase in climate-smart organic agricultural technologies to improve soil moisture content.
   (b) Institute structural changes to mitigate impacts of hydrological disasters.
4. Strengthening the evidence base
   (a) Undertake country-level surveillance of health impacts due to hydrological-related disasters for policy formulation and planning.

### 3.4 Indirect health effects associated with changes in ecosystem and social dynamics

Climate change can have secondary consequences by indirectly affecting the environment and ecosystems in which we live. The main secondary consequences are (1) agricultural losses; (2) changing disease patterns by enabling climate-sensitive vectors such as ticks, mosquitoes, etc. to colonise new regions; (3) decreased food production causing food insecurity as well as a shortage of clean water leading to increased food-borne disease; (4) spread of water-borne diseases; and (5) increases in air pollutants including pollen dispersal over a wider range resulting in respiratory disorders such as asthma and allergies.

#### 3.4.1 Food and nutrition security and agriculture

Food insecurity is defined as a state when a person lacks regular access to enough safe and nutritious food for normal growth and development and an active and healthy life (FAO, 2002). Food insecurity can be attributed to many causes, but this section will address food insecurity as a consequence of climate change. The combined effects of hydrological disasters leading to crop failure and causing food insecurity have been addressed in the previous sections, for example section 3.3.4 on drought and section 3.3.2 on floods. Another growing concern for crop failure, particularly in East Africa, is that the infestation and spread of voracious desert locusts destroying crops; Case Study 5 amply illustrates the issues involved.

**Case Study 5 Vulnerability to locusts in Kenya**

*Introduction*. This case study on the desert locust was chosen to illustrate the ecological relationship between climate changes and the expansion of a geographical range of a parasitic species. The desert locust outbreak in Kenya in 2020 was linked to changing climatic conditions: a prolonged bout of exceptionally wet weather, including several rare cyclones that struck Eastern Africa and the Arabian Peninsula in 2018, 2019 and 2020.

The two species of the desert locust, *Schistocerca gerardia* and *Zonocherus variegatus*, are migratory pest species with a preference for hotter climates and deep, moist, sandy or clay soils that are found in Africa. They can migrate over long distances as shown in the inset map of Figure 3.7, and they devastate crops on the way, thus threatening people's livelihoods, food security, the environment and economic development.

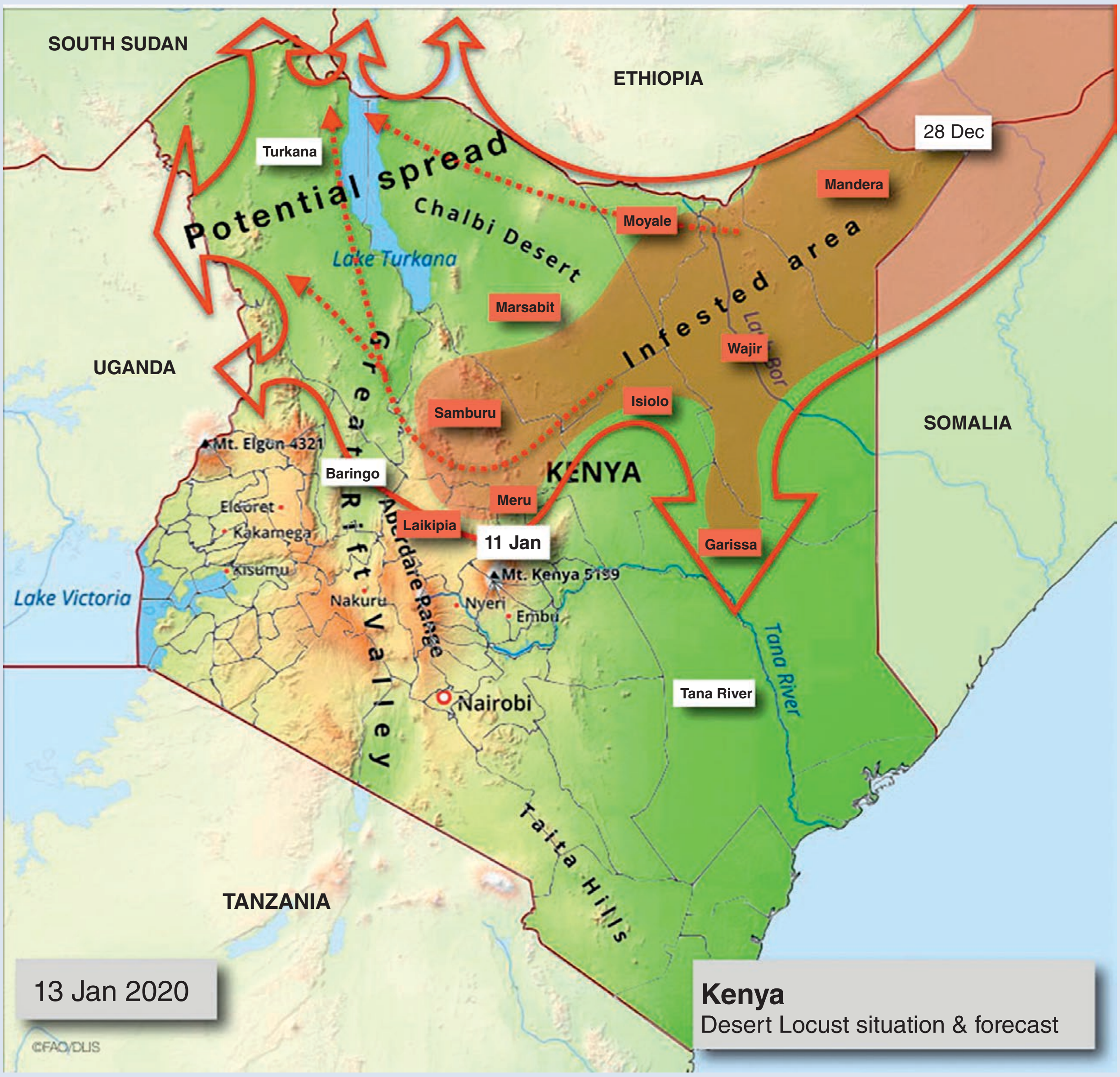



*Figure 3.7 Spread of locust swarms in 15 semi-arid counties of Kenya*[4].

*Desert locust predilection for Kenya*. Eighty per cent of Kenya's total land is arid and semi-arid, receiving less than 200 mm of annual rainfall in the northern, eastern and southeastern parts. The region is punctuated with short intervals of heavy rainfall that lead to seasonal vegetation sprouting. Such conditions frequently attract desert locust breeding. Two cyclones, Mekunu and Luban, brought heavy rains to the Arabian Desert and helped locusts breed freely. In 2019, large locust swarms entered northern Kenya from Ethiopia and Somalia (Figure 4.13). On 28 December 2019 and by February 2020 they had spread over 2400 km$^2$ in 15 semi-arid counties in central and northern Kenya, destroying 470,000 acres of crops and 741,000 acres of vegetation (World-Grain, 2020).

[4] Including Garissa, Isiolo, Mandera, Marsabit, Meru, Samburu and West Pokot.

*Locust impact on food security*. Between August and October 2019 over 1 million people were estimated to be in food crisis in northeastern and eastern Kenyan counties. Poor crop and livestock production and a rapid deterioration of rangeland resources resulted in fewer job opportunities in the farming sector, and high food prices which strained the incomes of most households (IPCC, 2020). Locusts damaged food security, mostly the maize (as shown in Figure 3.8) and pasture loss, especially for pastoralists in northern Kenya who were forced to move for long distances to the south in search of pasture. These scenarios worsened the food security status in semi-arid Kenya. Control measures for locusts require aggressive chemical spraying which affects humans, animals and the environment. These pesticides also kill beneficial insects such as bees and beetles, leading to no pollination and no fruit production.

*Figure 3.8 Locust outbreak threatens food security in semi-arid Kenya*[5].

*Lessons learnt from this case study*. This case study illustrates how the climatic changes of temperature and humidity can interact with the topology of the soil to accelerate the multiplication of pest vectors in expanding their geographic ranges, causing incalculable economic hardship to exposed communities and forcing many to migrate. It also illustrates that the adverse effect of climate change cannot be resolved at the country level alone; to eradicate the desert locusts in Kenya, a region-wide approach by the East and Horn of Africa countries is required through an early-warning signal for locust invasion.



Food insecurity has various health effects, the most direct of which is undernutrition. Undernutrition places people at risk of secondary or indirect health implications by heightening susceptibility to other diseases (WHO, 2008, 2012; World Bank 2017). For instance, malnourished children are more prone to infectious diseases including cholera and measles. With crop failure and rising food insecurity, the population is forced to resort either to imported energy-dense food or to locally produced unhealthy diets, putting them at increased risk of non-communicable diseases (see section 3.4.5). Malnutrition can also lead to child stunting, which is associated with reduced cognitive development and poor health into adulthood.

There are many reasons for food insecurity, but climate change remains the principal driver in Africa. The world produces more than enough food to feed its entire population, but food insecurity due to malnutrition is a growing crisis especially in developing countries. Moreover, millions of tonnes of food are being lost across the supply chain, from post-harvesting losses to processing and retail spoilage (Hodges *et al.*, 2011; Giovannucci *et al.*, 2012; Kumar and Kalita, 2017). This explicitly threatens food security and sometimes results in increases in global food prices. Besides these problems, climate change and other environmental risks often affect food security and nutrition. Consequently, the inhabitants of these areas cannot afford to purchase adequate food to sustain a balanced nutrition lifestyle or to reduce the risks of malnutrition and other non-communicable diseases (Lartey *et al.*, 2016; Tian *et al.*, 2016). Globally, the emphasis that access to a healthy and affordable diet that is environmentally sustainable is the desired outcome for food and nutrition security (Ha, 4 2018; FAO, 2019; FAO, 2020). However, the significant global challenges to food and nutrition security are compounded by the pressures of the growing world population, projected to reach over 9 billion by 2050, with 70% of it urban compared with 50% today (Liu, 2015). Climate change compounds the global environmental changes through extreme weather conditions and contributes to

[5] FAO (2020a).

economic inequity and instability (FAO, 2005; Pretty *et al*., 2010; UNESCO, 2010; Fischler *et al*., 2015).

A problem of this magnitude requires concerted interventions to adapt and mitigate. Climate change adaptation is, therefore, a challenge that adds to the many food security and nutrition issues that indigenous peoples in Africa are already facing. Commercial and non-commercial food sources, indigenous livelihoods, hunting and fishing would all be under growing threat. About 60% of food is locally grown in Africa, much of it by subsistence farmers. It is necessary to take stock of these problems and to focus on potential adaptation strategies that could be implemented (UNECA,2011). In designing such interventions, a balance must be reached in the following areas. While climate change is responsible for crop failure, unsustainable agricultural practices such as cattle raising can also contribute to climate change by emission of greenhouse gases. So, the emphasis should be on adopting a diet with less red meat consumption. At the same time, local communities must be empowered to extend their indigenous knowledge in promoting insect-based protein and planting drought- and pest-resistant crops.

*Current situation*. The FAO has reported the growing prevalence of undernourishment in the African region since 2017 (FAO, 2019). Some 256 million poor people live in Africa today; of these, 239 million live in sub-Saharan Africa and 17 million in northern Africa. Several reports have pointed to the underlying factors for rising food insecurity such as climate extremes, conflict, economic slowdowns and downturns. To be precise, in 2018 conflicts left 33 million people in 10 countries in need of urgent humanitarian assistance. Another 23 million needed assistance due to climate shocks, while over 10 million people were left in acute food insecurity due to economic shocks in Africa. For instance, the food security situation in Malawi improved compared with previous years. However, adverse weather conditions negatively affected maize production, which led to higher food prices, and left 3.3 million people in need of urgent food assistance (FAO, 2019, 2020, 2020a).

As an illustration, the 2016–17 drought conditions affected some communities in Kenya, particularly in the north and eastern arid and semi-arid areas. Additionally, adverse weather events, including flooding in April–May 2018, left 2.6 million citizens in desperate need of food aid and about 310,000 displaced. Mozambique has experienced extreme weather patterns, such as late rains, dry spells and irregular rains, which left 1.8 million people in need of emergency food assistance in 2018. Consecutive years of dry conditions and drought resulting from El Niño in 2015–16 left many households vulnerable in Madagascar. Dry weather in early 2018, pests, armyworm infestations in some countries and currency depreciation resulted in smaller stocks and higher staple food prices (Daron, 2014; CRED, 2019). Clearly one of the requirements of mitigating the adverse effects of drought is to be able to forecast the weather. Case Study 6 highlights the use of historical data and the involvement of farmers in mitigating the adverse effects of drought on crop failure.

*Projection*. While many African countries are making strides in decreasing hunger, development remains very slow in attaining the six primary nutrition targets of the Sustainable Development Goals (SDGs) monitoring framework and the sustainable nutrition goals of the World Health Assembly. Food insecurity has been on the rise in Africa in recent years, and the continent is not on track to eliminate hunger by 2030.

The impacts of climate change are evident in Africa. Several studies show that these impacts are more pronounced in countries such as Kenya, Ethiopia, Sudan, Mozambique, Nigeria, Benin and Angola. Studies have shown that, while levels of undernutrition are already high across the sub-Saharan African region, projections indicate that with warming of 1.2–1.7 °C by 2050, the proportion of the population that is undernourished will increase

## Case Study 6 Climate services for African agriculture

*Current situation*. The strong reliance on seasonal rainfall that farmers face for most agricultural production in African countries makes precipitation the most critical climatic variable for that sector. However, the effects of climate change on climate variability, in particular with regards to precipitation, are difficult to predict and quantify, in part because of the high natural variability in tropical seasonal rainfall and because robust data collection and attribution studies have mainly focused on mid-latitude regions (Marvel and Bonfils, 2013; Otto *et al*., 2015; Akinsanola *et al*., 2020). Nonetheless, there is broad consensus that climate change will lead to a redistribution of global precipitation, and to increases in the incidence and intensity of droughts in most of Africa (Marvel and Bonfils, 2013; Dosio *et al*., 2019; Akinsanola *et al*., 2020).

Climate services, the generation, provision and contextualisation of information and knowledge derived from climate research for decision-making, are increasingly recognised as crucial for the agricultural sector. They inform the decisions of breeders, farmers and relevant institutions, supporting a range of resilience-building interventions, and providing an enabling environment for the adoption of climate-smart agriculture (Dorward *et al*., 2015). Identifying the current norm of the area of an intervention is also a requisite to determine the efficacy of the adaptation strategies promoted (Cooper *et al*., 2008; Dorward *et al*., 2015).

The use of historical climate information is also important because of the common divergence between farmers' perceptions about seasonal climate variability and climate records, particularly with regards to precipitation, as illustrated in Figure 3.9 which shows historical seasonal rainfalls in the Kisumu district of Kenya. Farmers generally report a shortening of growing seasons; erratic onset of rains and uneven rain distribution; and an increase in both rainfall intensity and dry spells. However, these perceptions are often not corroborated by historical climatic
31 data (Moyo *et al*., 2012; Simelton *et al*., 2013; Muita *et al*., 2016; Dorward *et al*., 2020). Discrepancies have been attributed to several factors, which include the human tendency to selectively perceive and remember climatic factors as a function of their negative effect on livelihoods, and the difficulty of attributing individual causal effects to stresses experienced simultaneously (Glantz and Katz, 1977; Funk *et al*., 2013; Rao *et al*., 2019). One such example was the 2012 food emergency in eastern Kenya and southern Somalia caused by below-average March–May rainfall. Climate records show that this drought was not particularly severe, but it caused extreme suffering because it followed droughts in 2007, 2008, 2009 and 2011, which had already compromised the food security status of the region (Funk *et al*., 2013).

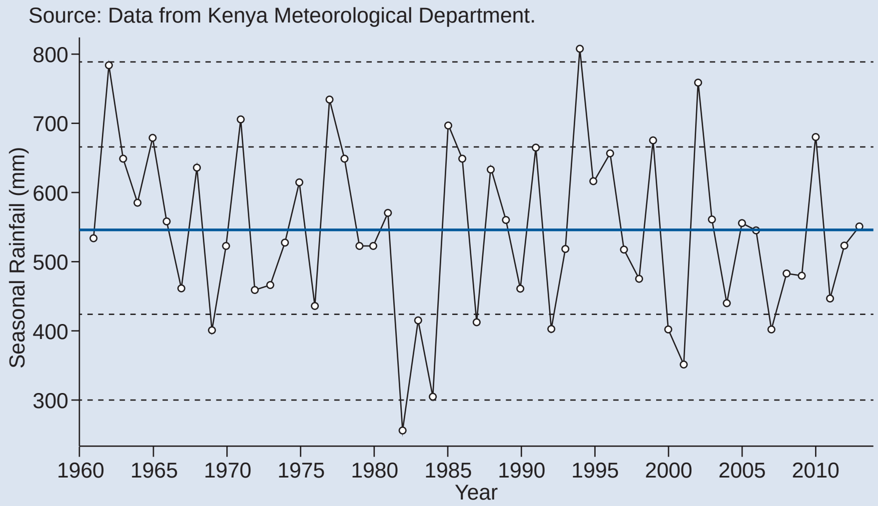



*Figure 3.9 Historical seasonal (March–May) rainfall totals in Kisumu, Kenya*[6].

Nevertheless, the fact that farmers do not give an objective indication of past weather trends is also one of the reasons why they should be engaged: their perceptions are subjective and provide an indication of the vulnerabilities experienced and of the key barriers to adaptation, which climate records alone would fail to indicate. In addition, this step also helps to incorporate in interventions traditional and indigenous ecological knowledge and is likely to increase the participation of farmers in the project and aid the subsequent dissemination of information in the wider community (Roncoli *et al*., 2009; Clarkson *et al*., 2019; Conway *et al*., 2019; Dorward *et al*., 2015).

However, the use of historical climate records to inform the planning stage of projects promoting climatic adaptation in the farming sector is still very limited. A study that explored the proportion of organisations in Kenya, Uganda and Tanzania promoting an increase of awareness of climate change showed that, out of 67 participants managing 102 community-level climate-related agricultural projects, and 3 NGOs, only 7% had used historical climate in the design and planning of the project (Dorward *et al*., 2015).

*Lessons learnt from this case study*. Historical climate analysis and the participation of farmers and other users of climate services are useful in situations that should be promoted to understand local climatic risks, key vulnerabilities and to identify the most appropriate adaptive measures. The co-production of solutions helps to better characterise and understand the problem context and facilitates the uptake of solutions in the community. Farmers can be trained to analyse graphs to determine, for example, the number of years a given crop would fail due to insufficient rain in a period, such as in the Participatory Integrated Climate Services for Agriculture (PICSA) programme.

[6] From Kenya Meteorological Department.

by 25–90% compared with the present (Lloyd *et al*. 2014). Projections also indicate that the proportion of moderately stunted children in the region will not increase above the 2010 baseline level of 16–22% in a scenario without climate change, but with 1.2–1.7 °C above pre-industrial values by 2050 could increase by 9%. The proportion of severely stunted children, which was estimated at 12–20% in 2010, is projected to decrease by 40% without climate change and by only10% with climate change (Lloyd *et al*. 2014).

### 3.4.2 Specific recommendations for agriculture and food security

1) Institutional policy
   (a) Recognise food security as a multi-origin problem and plan accordingly.
2) Health adaptation
   (a) Institute EWARS to anticipate the necessary surge capacity for food insecurity.
   (b) Strengthen health systems to cope with surges in malnutrition and food-insecurity-related illnesses.
   (c) Promote initiatives to switch from diets high in red meat to insect- and plant-based proteins.
3) Mitigation
   (a) Empower local communities and farmers to use indigenous farming practices and planting pest- and insect-resistant crops.
   (b) Phase in farming practices to reduce the emission of GHGs.
4) Strengthening the evidence base
   (a) Undertake country-level surveillance of health impacts due to food security disasters for policy formulation and planning.

### 3.4.3 Climate-sensitive infectious diseases

Infectious diseases are prime targets for amplification by climate change. Climate changes are associated with temperature rise, altered rainfall patterns and humidity, and these climatic factors may lead to an increase in the reproduction rate of the infectious agent and the proliferation rate of the biological vectors transmitting the infectious agent, extending its geographical range by altering the ecosystem and shifting the pattern and epidemiology of the disease
(Omazic *et al*., 2019). In these sections, we 5
review the evidence for three groups of infectious climate-sensitive diseases: zoonotic diseases transmitted by animal vectors; vector-borne diseases transmitted by insects and mosquitoes; and infectious food- and water-borne diseases. The dynamics of transmission of these diseases are illustrated in Figure 3.10.

### 3.4.4 Zoonoses

Zoonoses are infectious diseases that are transmitted from animals to humans and comprise pathogenic microorganisms such as bacteria, parasites and fungi (WHO, 2020a). Emerging zoonotic diseases contribute to the public health impact by causing outbreaks, morbidity and mortality, resulting in societal and economic disruptions. It has been estimated that more than 70% of current infections are due to zoonoses; hence they are important in a climate change context as both
human and animal health are at risk (Jones 6
*et al*., 2008).

In recent decades, there have been various zoonotic disease outbreaks, including zoonotic influenza (bird flu), pandemic human influenza (H1N1), Middle East respiratory syndrome (MERS), severe acute respiratory syndrome (SARS) and, most recently, coronavirus disease 2019 (COVID-19). Several major anthropogenic drivers of zoonotic disease emergence, including climate change, have been identified (UNEP, 2020); however, determining the particular drivers leading to zoonotic occurrence is complex. UNEP released a special volume of their *Frontiers* report series entitled ‘Preventing the next pandemic: Zoonotic diseases and how to break the chain of transmission’ (UNEP, 2020). Climate change influences the geographical distribution of zoonotic diseases, and extreme weather events such as floods and droughts increase the risks of infectious disease epidemics

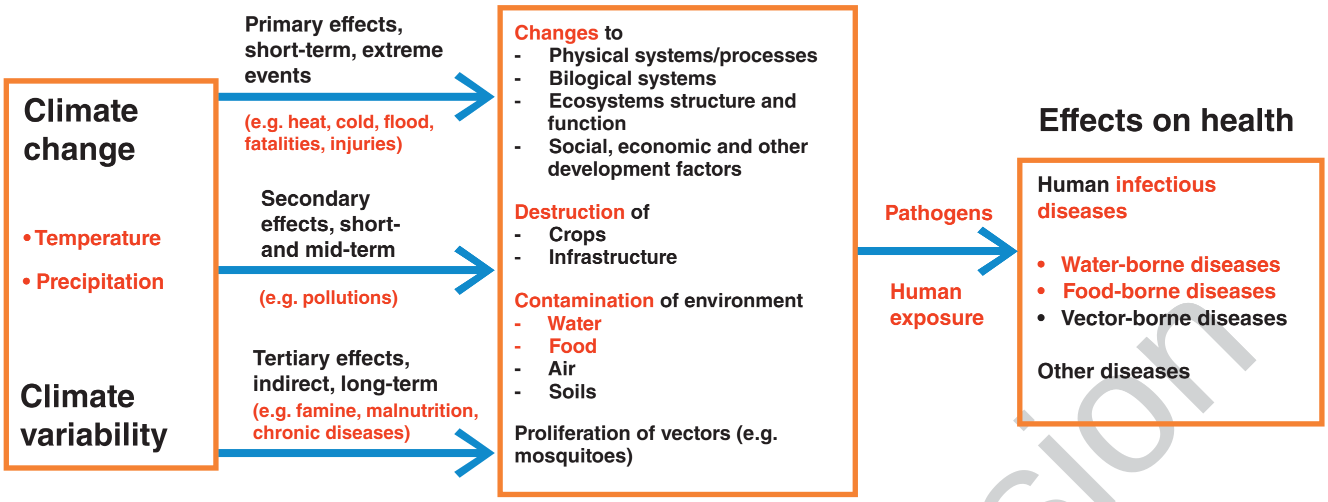



*Figure 3.10 Interrelationships of infectious diseases and exposure pathways*[7].

being triggered. Changes in the prevalence of species caused by climate change can occur. The changes in biodiversity are driven by multiple factors including urbanisation and the ecological disturbances caused thereby (Mordecai *et al*., 2019).

Travel and transportation of animals (e.g. to markets where wildlife is sold) will allow a rapid intercontinental spread of emerging zoonoses (UNEP, 2020). Zoonoses can be introduced at any point during the transfer of animal meat between hunting, harvesting, butchering and handling. When meat is opportunistically harvested, there is also a risk of transmission, such as in the case of the Ebola outbreak from 2013 to 2016 in Central Africa when infected gorilla and chimpanzee cadavers were handled (Leendertz *et al*., 2016). Pathogens that pass between the diverse species range exhibit greater 'host plasticity' and are more likely to spread to humans and promote a pandemic. Wildlife use, trade and consumption brings with them zoonotic risks. The increased encroachment of humans into natural habitats has been spurred by the increase in population size, with Africa experiencing the highest rate of population growth. It is expected that Africa will account for more than half of the world's population growth between 2017 and 2050 (World Bank, 2017). This consequently increases the risk of animal-to-human disease transmission as the greatest risk factor for transmission spill-over remains the proximity to and interaction with animals (Olivero *et al*., 2017; Rulli *et al*., 2017). Wildlife harvesting, trade and consumption have been practised for centuries. Wild animals have been hunted and captured for human sustenance, recreation and sale of body parts and/or their derivatives. Many households in Africa consume wild meat, including herbivores, reptiles and rodents. A survey conducted in Brazzaville, Democratic Republic of the Congo, estimated that approximately 83% of the sampled households consumed wild meat (Mbete *et al*., 2011). There is also an increase in the harvesting and consumption of aquatic animals. Many factors drive the consumption of wild meat, including the increasing human population and the consequent increased demand for income and protein-rich food, which may not necessarily be satisfied with traditional resources alone, as well as job and income security. Wild meat contributes approximately ZAR9 billion annually to South Africa's gross domestic product and employs over 100,000 people (DEA, 2019).

Wild meat and live wild animals are sold in traditional markets which may not necessarily



[7] Adapted from Cissé (2019) and Moors *et al*. (2013).

adhere to adequate biosafety measures, thereby increasing the risk of zoonotic disease emergence.

### 3.4.5 Vector-borne diseases

Vector-borne diseases are primarily transmitted by insects and mosquitoes. The main vector-borne diseases considered here are malaria, dengue, yellow fever, chikungunya and Rift Valley fever.

*Disease burden*. Malaria, yellow fever, dengue and chikungunya can cause mild febrile illness or debilitating diseases including meningitis. Rift Valley fever infects both humans and cattle; it affects the lives and livelihoods of the pastoral communities relying on a livestock economy who are highly vulnerable to the threat of disease to their livestock (Kasye *et al.*, 2016).

Vector-borne diseases are of tremendous public health and socio-economic importance in Africa, as they are collectively responsible for high disease burden and mortality resulting in absenteeism from schools and workplaces, increased costs of health care and loss of productivity. For instance, the WHO African region contributed 93% of the global malaria burden and 94% of the global malaria death (Beguin *et al.* 2014) and some 771 million people are projected to be at risk of malaria in sub-Saharan Africa by the year 2050. Similarly, some 1,410 million people will be at risk of dengue fever, a figure that represents about 30% of the global total (Åström, 2014). Although yellow fever is widely spread in tropical regions of Africa and South America, 90% of the global burden is in Africa, mainly from 27 high-risk and 8
9 moderate-risk countries (Barrett and Higgs, 2007). Although the incidence of yellow fever has been considerably reduced since the introduction of yellow fever, the disease is still persistent in Africa: for example, a meta-analysis showed its incidence per 100,000 population ranged from less than 1 case in Nigeria, fewer than 3 cases in Uganda, 13 cases in the Democratic Republic of the Congo, 27 cases in Kenya, 40 cases in Ethiopia, 46 cases in Gambia, 1,267 cases in Senegal to 10,350 cases in Ghana. Case fatality rates associated with yellow fever outbreaks ranged from 10% in Ghana to 86% in Nigeria. The mortality rate ranged from 0.1 per 100,000 in Nigeria to 2,200 per 100,000 in Ghana (Nwaiwu *et al.*, 2021). 10

*Links between climate change and vector-borne diseases*. Understanding how climate change affects human health and the transmission of vector-borne diseases requires studying the entire ecosystem encompassing the vector–pathogen–human relationship at certain environmental conditions (Caminade *et al.*, 2016). Changes in temperature and rainfall (intensity, extremely low or high values and duration of these extremes) may create favourable conditions for the proliferation of animal reservoirs as vectors and hence the diseases' transmission. Climate change may also affect humans through drought, storms and flooding as well as socio-economic activities such as irrigation agriculture, fishing practices and coastline settlements by increasing population vulnerability to vector-borne diseases (Fouque and Reeder, 2019).

*Projection and risk of future burden*. Different studies have assessed the impact of climate change on malaria transmission. A recent study from Zimbabwe predicted Southern Africa will be free from malaria by 2040 due to the 'drying trend' caused by increasing temperature. Likewise, the highlands of Africa, particularly Eastern Africa, will be malaria endemic largely due to global warming but also to land use and drug resistance (Hay *et al.*, 2002; Siraj *et al.*, 2014; Ngarakana-Gwasira, 2016). Pascual *et al.* (2006) used temperature data from 1950 to 2002 at four high-altitude sites in East Africa and statistical analyses with dynamic vector modelling to show that there is a significant warming trend which in turn favours the population dynamics of the mosquito vector in these highlands. In 2009, malaria in Kenya (where 70% of the population were living in a malaria-prone area) accounted for about 30% of all outpatient visits and 19% of all hospital admissions.

In a projection study where an average temperature increase of 2.3 °C is assumed and with no mitigation and adaptation measures taken, the Kenyan population affected by malaria will increase by 74% annually. That means in 2055 an extra 5.8 million people will be affected and 15,700 extra deaths annually will occur because of malaria, assuming the same population and incidence rate as in
11 2009 (Downing, 2009). Prediction of malaria cases for 2030 and 2050 for different regions of sub-Saharan Africa shows that Western, Eastern and Central African regions will be significantly affected but Southern Africa will be more or less free from malaria as predicted by Ngarakana-Gwasira *et al*. (2016).

Increasing temperature and rainfall favourably affect the breeding pattern of the vector, *Aedes aegypti*, for transmission of dengue fever. As a result of a changing climate, by 2080 about 6 billion people will be at risk of contracting dengue fever as compared with an estimated 3.5 billion that will have dengue fever if the climate remains the same (Hales *et al*., 2002). Similar to the vulnerability to malaria, Western, Eastern and Central Africa will be most affected by dengue fever whereas the Southern Africa region will be significantly less affected.

Urban yellow fever is the vector-borne disease most linked to climate change. Hence the impact of climate change on this disease is briefly described here. Like dengue fever, an increase in temperature and rainfall is associated with increased vector reproduction and hence more cases of yellow fever. Gaythorpe *et al*. (2020) predicted that Eastern and Central African regions will have drastic proportional increases in burden and annual deaths caused by yellow fever. The number of deaths per year may also increase by 10–40% for different climate change scenarios (WHO, 2018).

Rift Valley fever was reported in Kenya in the 1900s. An outbreak was reported in Egypt: Rift Valley fever virus was introduced to Egypt through infected livestock trade along the Nile irrigation system. In 1997–98, a major outbreak occurred in Kenya, Somalia and Tanzania following an El Niño event and extensive flooding. Following infected livestock trade from the Horn of Africa, Rift Valley fever spread in September 2000 to Saudi Arabia and Yemen, marking the first reported occurrence of the disease outside the African continent and raising concerns that it could extend to other parts of Asia and Europe (WHO, 2019). The disease is believed to be influenced by climate change. For example, epidemics in the Horn of Africa are associated with altered rainfall patterns. Additional climate variability and change could further increase its incidence and spread.

Two other vector-borne diseases, Zika and chikungunya, both of which originated in Africa, have spread globally. They are believed to have a climate-driven component, as outbreaks of them have occurred outside their ecozones.

### 3.4.6 Food- and water-borne diseases

*Health and related impacts*. Food- and water-borne infectious diseases are caused by infectious pathogens such as bacteria, viruses and parasites, as well by chemical contaminants in water and food. This may result in severe diarrhoea, dehydration and include complications of meningitis. Other complications of food- and water-borne infectious diseases include disability, hospitalisation, absence from school or work and economic hardships. It has been estimated that Africa counts 91 million people falling ill and 137,000 dying per year by these diseases (Cissé, 2019).

Food and water contamination are of relevance among the environmental factors contributing to this burden. Diarrhoeal diseases, major food- and water-borne diseases, represent 22% among the main diseases with the largest environmental contribution in children under 5 years of age (WHO, 2015a, 2018a). Previous studies have highlighted that climate change will alter globally, including in Africa, the incidence of food- and water-borne diseases and diarrhoeal diseases (Lake and Barker, 2018; Levy *et al*., 2018; Schijven *et al*., 2013).

*How climate change affects and food- and water-borne diseases*. Food- and water-borne diseases are highly sensitive to rising temperature and water, and therefore they are susceptible to the effects of climate change. The IPCC Special Reports on the Impacts of Global Warming of 1.5 °C stipulate that climate-related risk to health, livelihoods, food security, water supply, food- and water-borne infectious diseases, human security and economic growth are projected to increase with global warming of 1.5 °C and to further increase at 2 °C (IPCC, 2018; AR6- UNFCCC, 2020) in many regions of the world, including sub-Saharan Africa. The pathways through which climate change and climate variability will affect human health are highlighted in
12 Figure 3.10 (Cissé *et al*., 2011). Evidence suggests that the onset and transmission of food- and water-borne diseases, particularly diarrhoeal ones, can be influenced by many factors including climatic parameters such
13 temperature and precipitation (Singh *et al*., 2003; Lama *et al*., 2004; Hashizume *et al*., 2007; Onozuka *et al*., 2010; Levy *et al*., 2018). During extreme weather events, water sources can become contaminated with microorganisms such as bacteria (e.g. *Salmonella* spp., *Shigella* spp., *Escherichia coli*, *Campylobacter* spp., *Vibrio cholera*), viruses (e.g. rotavirus, norovirus, enteric adenovirus) and parasites (e.g. *Giardia*, *Cryptosporidium*, *Cyclospora*) that can cause gastrointestinal infections (Acheson, 2009). Furthermore, studies of the effects of temperature increase on diarrhoeal disease in Lima, Peru, have shown that the incidence of diarrhoeal disease increases 8% for every 1 °C temperature increase; these observations support the role of the 1997–98 El Niño climate change event on infectious diseases (Checkley *et al*., 2000).

Temperature rise may provide an optimum environment for microorganism reproduction
14 cycles and algal blooms (Moors *et al*. 2013; Wu *et al*., 2016). Pathogens such as bacteria favour warmer temperatures (Freeman *et al*., 2009; El-Fadel *et al*., 2012). Increased temperatures may increase the probability of food spoilage, and concurrent temperature-related changes in food storage and consumption practices may affect disease
risk (D'Souza *et al*., 2004; Tirado *et al*., 2010). 15
Water consumption rates may also increase during warmer periods of the year, increasing the risk of pathogen ingestion in regions with poor quality drinking water. While the ambient temperature may affect pathogen survival and host behaviour, increased or extreme rainfall can directly affect the transport of pathogens and can affect the existing water and sanitation infrastructure, altering human exposure patterns (Levy *et al*., 2016).

As illustrated in Figure 3.10, climate change may cause shifts in temperature and precipitation, which affect the dissemination of water-borne pathogens. Several studies argue that floodwaters can spread pathogens within watersheds and heavy rainfall events can lead to saturation of the subsurface, which facilitates water transport of pathogens to the surface or through groundwater (Ferguson *et al*., 2003; Auld *et al*., 2004; Dorner *et al*., 2006; Fong *et al*., 2007). Heavy rainfall and flooding can increase the vulnerability of water sanitation and hygiene systems, affecting pathogen transmission through sanitation and/or drinking water treatment infrastructures (see, for example, Cissé *et al*., 2019).

Decreased rainfall or drought, coupled with water scarcity, limits dilution and may, thus, increase the fraction of wastewater in surface water, leading to consumption of lower quality water due to increases in the concentrations of pathogens in both drinking and irrigation water sources (Moors *et al*. 2013; Levy *et al*., 2016). Populations relying on these contaminated water resources experience increased outbreaks of water-borne diseases, including diarrhoeal diseases (Hashizume *et al*., 2007; El-Fadel *et al*., 2012). Water scarcity has been shown to have a range of health problems, including diarrhoea (Hales *et al*., 2014). In periods of decreased water availability, people must revert to poor quality

water sources (Jofre *et al.*, 2009). For example, it has been observed that cholera may develop and spread in drought-stricken areas where lack of water leads to poor sanitation
16 (Schurman, 2010).

*Current disease burden in Africa.* The effective burden of food- and water-borne infectious diseases is underestimated because of underreporting and the complexity of the pathways and factors involved in their transmission, particularly in developing
17 countries, including sub-Saharan Africa (Cissé *et al.* 2018).

*Food-borne diseases in sub-Saharan Africa*. Ninety-one million illness episodes and 137,000 deaths every year are attributable to food-borne diseases, and diarrhoeal diseases were responsible for 70% of the burden of these (WHO, 2015, 2015a). Estimating the burden of food-borne diseases is complicated because most of the agents causing them are not transmitted only by food (Hald *et al.*, 2016). As water plays a major role in the burden of these diseases, the separation of food and water as exposure vehicles is difficult, particularly at the community level (Cissé, 2019).

*Water-borne diseases (WBDs)*. WBDs are a major public health concern globally. WBDs are those transmitted by ingestion of contaminated water and are highly linked to the quality of drinking water, poor sanitation and poor hygiene. WBD outbreaks, particularly infectious intestinal diseases, have been attributed to various pathogens and drinking water system characteristics (Bless *et al.*, 2016; Ligon and Bartram, 2016). The main driver of the burden of WBDs is drinking water containing pathogenic microorganisms (see David *et al.*, 2014; Murphy *et al.*, 2014). In many countries, including sub-Saharan Africa, health systems face difficulties in the collection and reporting of WBDs. This explains why globally reported numbers generally greatly underestimate the real incidence of WBDs (Leclerc *et al.*, 2002). Important WBDs include diarrhoeal diseases, cholera, shigella, typhoid, hepatitis A and E, and poliomyelitis, and can all be caused by pathogens in water (WHO, 2015a).

In 2016, diarrhoeal diseases alone were the eighth leading cause of mortality, responsible for more than 1.6 million deaths (GBD 2016 Causes of Death Collaborators). More than a quarter (26.93%) of diarrhoeal deaths occurred among children under 5 years of age, and about 90% of diarrhoeal deaths occurred in South Asia and sub-Saharan Africa (GBD 2016 Causes of Death Collaborators). In sub-Saharan Africa, about 1 out of 10 children died because of diarrhoea in 2016, causing an estimated burden of 25 million disability-adjusted life-years. In fact, 90% of diarrhoeal diseases are linked to a lack of safe drinking water, environmental pollution and poor sanitation (WHO, 2015c). Climate change is likely to exacerbate the risks of diarrhoeal and other food- and water-borne diseases in low- and middle-income countries, including sub-Saharan Africa, in the future (IPCC, 2018).

*Projections*. Food- and water-borne infectious diseases are likely to be amplified by climate change, particularly in regions of Africa where the temperature is rising and the precipitation pattern is affected. WBDs, particularly cholera/diarrhoeal diseases, are among the primary expected health impacts of climate change (Levy *et al.*, 2016; Lake and Barker, 2018).

Cholera is primarily associated with weather and climate variability, suggesting possible changes in incidence and geographical range with climate change (Olago *et al.*, 2007; Murphy *et al.*, 2014). Several studies have highlighted that cholera is associated with heavy rainfall in coastal West African countries
and South Africa (de Magny *et al.*, 2007, 18
2012; Mendelsohn and Dawson, 2008). In 19
East Africa, an increase in temperature or rainfall was observed to increase the number
of cholera cases (Luque Fernández *et al.*, 2009; 20
Reyburn *et al.*, 2011). There are projected 21
increases in precipitation in areas in Africa, for example West Africa where cholera is already endemic. This will possibly lead to more frequent cholera outbreaks in the sub-regions (Niang *et al.*, 2014).

Kolstad and Johansson (2011) observed an association between rates of diarrhoea and high temperatures, and projected an increase of 8–11% in the risk of diarrhoea in the tropics and subtropics in 2039 because of climate change. In 2014, the WHO projected an additional 48,000 deaths in children aged below 15 years, mainly due to diarrhoeal diseases by 2030 and 33,000 deaths by 2050 (WHO, 2014). In sub-Saharan Africa, an additional 31,000 deaths in children aged below 15 years, mainly due to diarrhoeal diseases, are projected by 2030 and 24,000 deaths by 2050 (WHO, 2014). The impacts are particularly concentrated in Eastern and Western Africa where diarrhoeal diseases and cholera are already endemic.

### 3.4.7 Specific recommendations for infectious and vector-borne diseases[8]

(1) Institutional policy
   (a) Institute intersectoral collaborations across relevant ministries (environment, agriculture, etc.) during vulnerability assessment and adaptation by such tools as HiAP and the One Health approach.
(2) Health adaptation
   (a) Institute EWARS to anticipate the necessary surge capacity for infectious diseases including vector-, food- and water-borne diseases.
   (b) Strengthen the health system to cope with surge from epidemics due to the above conditions.
   (c) Promote adaptative measures for control of vector-borne diseases by vaccination where relevant, bed nets and environmental hygiene.
(3) Mitigation
   (a) Control vector density and ensure water sanitation and food hygiene.
   (b) Institute structural changes to mitigate impacts of hydrological disasters.
(4) Strengthening evidence base
   (a) Undertake epidemiological research including modelling to sensitise policy-makers to the health, social and economic gravity of climate-sensitive infectious diseases.

### 3.4.8 Non-infectious non-communicable disease threats

Non-communicable diseases (NCDs) represent a constellation of diseases that are grouped together because they share the common exposure and risk factors of unhealthy diets and lifestyles (WHO, 2021). The WHO classifies NCDs into four groups: (1) cardiovascular diseases, i.e. heart attacks and stroke which kill 17.9 million annually; (2) cancers, which kill 9.0 million people annually; (3) respiratory diseases, comprising chronic pulmonary obstructive disease and asthma which kill 3.9 million; and (4) diabetes, which kills 1.6 million annually.



#### *3.4.8.1 Cardiovascular diseases, heart attacks and stroke*

*Current situation*. Cardiovascular diseases are a leading cause of mortality and morbidity in adults, and stroke is the largest single cause of disability in most African countries (WHO, 2021), In 2015, about 17.7 million people died from cardiovascular diseases (representing 31% of all global deaths); 7.4 million of the deaths were due to coronary heart disease and, 6.7 million deaths were due to stroke (WHO, 2002; Mensah *et al.*, 2015). 22

*Projection*. Evidence indicates that warmer and drier climates in sub-Saharan Africa will cause increased heat and bushfires, resulting in increased air pollution which may increase the risk of respiratory and cardiovascular incidences among vulnerable groups including asthmatics, children and the elderly in Africa by 2030 (Friel, 2011). 23

#### *3.4.8.2 Metabolic disorders: diabetes, obesity and malnutrition*

*Current situation*. According to the 9th edition of the International Diabetes Federation Diabetes Atlas, about 19 million adults aged

[8] Including water and food-borne diseases

between 20 and 79 years were living with diabetes in Africa in 2019, representing a regional prevalence of 3.9%, while 45 million adults have impaired glucose tolerance which places them at high risk of developing type 2 diabetes (International Diabetes Federation, 2019). The Africa region has the highest percentage of undiagnosed people, with 60% of adults living with diabetes not knowing their status (International Diabetes Federation 2019).

*Projection*. According to projections of the International Diabetes Federation, there will be 29 million adults with diabetes in Africa by 2030, and 47 million by 2045. The number of people with impaired glucose tolerance will be 67 million in 2030 and 110 million by 2045. These figures correspond to regional diabetes prevalence rates increasing from 3.9% in 2019 to 4.1% in 2030, and to 4.4% in 2045 (International Diabetes Federation, 2019).

### *3.4.8.3 Cancer*

*Current situation*. Africa records over 600,000 cancer deaths annually. According to the WHO cancer registry, Uganda reported 32,617 cancer cases in 2017, with 151 deaths per 100,000 people. Tanzania reported 42,060 cases with 132 deaths per 100,000 people. Kenya had the highest number of cancer cases in the region with 47,887 and 176 deaths per 100,000 people. Colorectal cancers are common in sub-Saharan Africa, particularly in West Africa, Southern Africa and Zambia. The International Agency for Research on Cancer estimated that the incidence of breast cancer was 27 per 100,000 women in Central Africa and 39 per 100,000 women in Southern Africa (Adeloye *et al*., 2018).

Skin cancer is linked to solar ultraviolet radiation especially in people with fair skin. South Africa experiences summertime ultraviolet index values greater than 10 and has recorded high incidences of skin cancer in the population group with fair skin (Friel *et al*., 2010). In 2002, African countries registered the highest average daily ambient ultraviolet radiation level in the world, and overexposure to ultraviolet radiation 'caused the loss of approximately 2.5 million DALYs [disability-adjusted life-years] (0.2% of the total global burden of disease) and 60,000 premature deaths'.

Eye-related NCDs include cataracts and eye cancer caused by exposure to ultraviolet radiation (McMichael *et al*., 2006).

### *3.4.8.4 Chronic respiratory diseases: asthma and chronic obstructive pulmonary disease*

*Current situation*. The report 'Lung Health in Africa' indicates that Africa carries a high burden of chronic respiratory disease morbidity and mortality. Asthma is the commonest NCD in African children, with the prevalence varying between countries (Ethiopia 9.1%, Kenya 15.8%, Nigeria 13.0%, Mozambique 13.3% and South Africa 20.3%) (Ahmed *et al*., 2017). Asthma is triggered by extreme heat and characterised by attacks of breathlessness, wheezing and chronic coughs. Chronic obstructive pulmonary disease has the highest prevalence rates in African adults.

*How climate change and NCDs are related*. NCDs and climate change are interlinked by complicated exposure pathways and they have both direct and indirect health and socio-economic consequences (Friel *et al*., 2010; Nugent and Fottrell 2019). Climate parameters linked to NCDs in Africa include (1) high temperature, (2) air pollution, (3) exposure to ultraviolet radiation and (4) droughts. The empirical observation from a Dutch study corroborates the relationship between temperature rise and diabetes. This established that every 1 °C rise in outdoor temperature is associated with far more than 100,000 new diabetes cases per year in the USA alone for the period 1996 and 2009 (Blauw *et al*. 2017). Air pollution and heat lead to increases in chronic respiratory disease including asthma and chronic obstructive pulmonary disease in Africa, with some 1.2 billion people being exposed to toxic biomass fuel and ambient air pollution (Heather and Aluoch, 2016). Exposure to ultraviolet radiation leads to increases in skin cancers and eye cataracts. Droughts result in malnutrition, diabetes and obesity; extreme weather events result in heart attack, stroke, hypertension, depression, injuries and mental health issues (ClimDev-Africa, 2013, 2013a).

*Africa's vulnerability to NCDs, resulting from climate change*. The high prevalence of climatic hazards concomitant with climate change could amplify the pre-existing levels of NCDs. For example, sub-Saharan Africa has high prevalences of hypertension (48%), diabetes (5.1%) and obesity (20%) (Hebe *et al*., 2019; Rother *et al*., 2020). In addition, Africa has weak adaptive capacity because of endemic poverty, complex governance and institutional dimensions; limited access to capital, including markets, infrastructure and technology; ecosystem degradation; and complex disasters and conflicts. (Boko *et al*., 2007; Hebe *et al*., 2019). According to the Climate Change Vulnerability Index for 2015, 7 of the 10 countries most at risk from climate change effects in Africa are Guinea-Bissau, Sierra Leone, South Sudan, Nigeria, Democratic Republic of the Congo, Ethiopia and Eritrea.

The changing disease profile of Africa from communicable disease to a non-communicable
24 one (Mudie *et al*., 2017) is partly due to a shift from healthy diets to unhealthy ones as a result of climate change. Africa provides 60% of the food supply to her population with the remaining 40% relying on food imports and food aids from USA (biotech maize) which are cheap sources of calories that increase the risk of obesity and diabetes. To mitigate the impact of drought on poverty, food security and malnutrition, South Africa, Kenya, Malawi, Nigeria, Ghana, Ethiopia and Uganda have approved the growing and consumption of biotech crops (maize, rice and potatoes) which are high in carbohydrates and associated with obesity that causes diabetes. Malnutrition, the largest contributor to climate-related deaths globally, causes 1.7 million deaths per year, particularly in sub-Saharan Africa (ClimDev-Africa, 2013; Grinspoon, 2020).

By 2030 the western Sahel region with its prolonged droughts will have increased incidences of malnutrition, asthma, skin cancers, dehydration and heatstroke. Central Africa, with increased rainfall, storms and floods, will get increased incidences of asthma, cardiovascular diseases and injuries. West Africa, identified as a climate change hotspot, will get reduced crop yields, food scarcity and increased cases of malnutrition. If the global mean temperature reaches 2 °C, sub-Saharan Africa will experience extreme weather events leading to a fivefold increase in incidences of all types of NCD by 2090 (IPCC, 2007; Nangombe *et al*., 2019; Shepard, 2019).

### 3.4.9 Specific recommendations for non-communicable diseases

1) Institutional policy
   (a) Foster partnerships to implement the SDGs that include, *inter alia*, climate actions and NCDs.
2) Health adaptation
   (a) Institute EWARS to anticipate the necessary surge capacity for NCDs.
   (b) Strengthen health systems to cope with surge in NCDs.
3) Mitigation
   (a) Introduce measures that have synergies across sectors and reduce burden of NCDs. These include greening of transport, urban planning, agricultural and energy sectors: for example, reducing consumption of animal products simultaneously reduces GHG emissions, leads to less saturated fat consumption and reduces risks of NCDs.
4) Strengthening the evidence base
   (a) Undertake country-level surveillance of the burden of NCDs.

### 3.4.10 Environmental toxicology: air pollution and other pollutants

The air we breathe can be polluted by a variety of pollutants to a level that exceeds WHO standards and puts millions of people at risk of disease and death (WHO, 2020). Climate change is affecting the quality of the air we

**Table 3.2 Global and African deaths due to air pollution**

| | Deaths attributable to air pollution (95% uncertainty interval) | | Proportion of global deaths in Africa |
|---|---|---|---|
| | Africa | Global | |
| All air pollution | 1.1 million (932,000–1.3 million) | 6.7 million (5.9 million–7.5 million) | 16.3% |
| Ambient $PM_{25}$ pollution | 393,419 (288,615–491,042) | 4.1 million (3.4 million–4.8 million) | 9.3% |
| Household air pollution | 697,000 (526,000–879,000) | 2.3 million (1.6 million–3.1 million) | 30.3% |
| Ambient ozone pollution | 11,230 (4800–18,300) | 365,000 (175,000–564,000) | 3.1% |

Data from the 2019 Global Burden of Disease Study. PM=particulate matter.



breathe and has reached a global proportion beyond regional boundaries. Air pollution is the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the air. Table 6.1 in Appendix 2 lists the various sources of air pollutant, their exposure pathways and health effects. For simplicity, we can apportion air pollution as indoor (also called ambient) and outdoor (also called urban). But a person is usually exposed both to indoor and to outdoor pollution, although to different levels, depending on the settings.

*Disease burden for Africa*. The main causes of deaths attributable to air pollution are lung cancer, chronic obstructive pulmonary diseases, lower respiratory infection, ischaemic heart disease and stroke, and neonatal complications (GBD, 2019).

Air pollution is now the second largest cause of deaths in Africa, exceeded only by AIDS (GDB, 2019). The African continent accounted for 16.3% of the global deaths due to all types of air pollution in 2019; this represents some 1.1 million deaths in Africa alone (Fisher *et al*., 2021). A breakdown of the number of deaths is shown in Table 3.2, which reveals that out of the 1.2 million deaths attributable to air pollution in Africa, 697,000 are attributable to indoor air pollution, representing some 30% of the global deaths attributable to it, whereas the number of deaths attributable to ambient air pollution was 394,000.

*3.4.10.1 Indoor air pollution*

Indoor air quality is defined as the quality of the ambient air within buildings and structures. Clean air is vital for the well-being and comfort of building occupants (USEPA, 2014a). The time spent by people in both home and work environments has increased during recent decades (Owen *et al*. 2010). The main sources of indoor air pollution include a range of respirable particles in the form of $PM_{2.5}$ (particulate matter of sub-2.5 µm size), oxides of nitrogen, carbon monoxide and dioxide, volatile organic substances as well as those from biological allergens and infectious agents such as respiratory viruses.

*Challenges of indoor air pollution in Africa*. indoor air pollution is due to many air pollutants, which are listed in Table 3.2. An estimated 7.2 million people in Africa are dependent on polluting fuels such charcoal, kerosene and solid fuels, including biomass in various forms such wood, animal dung and crop waste, for heating, cooking and lighting. The proportion of deaths among the exposed 7.2 million people represents 60% of all air pollution-related deaths across Africa (Fisher *et al*., 2021). This number is projected to increase significantly by the end of the decade (von Schirnding *et al*., 2002; Kammila *et al*., 2014). Solid fuels emit large amounts of pollutants including particulate matter, carbon monoxide, metals, hydrocarbons, oxygenated organic compounds and chlorinated organic compounds into the household environment (Gall *et al*., 2013). Therefore, occupants face several potential health risks related to indoor air pollution and the numbers of those at risk are expected to increase in the future.

Indoor air pollution may be reduced by adapting to cookstoves and the energy source used, as well as the characteristics of the dwelling. For example, in South Africa in winter, a household burning solid fuel, with no insulation in the roof, had indoor $PM_4$ concentrations ranging from 60 to 207 $\mu g/m^3$, while a house burning non-solid fuel, with a ceiling and insulation that used electricity, experienced $PM_4$ concentrations between 15 and 84 $\mu g/m^3$ (Adesina *et al*., 2020). The indoor air pollution seen in the latter may have entered from outdoors or from other indoor air pollution sources.

Another example of reducing indoor air pollution by adaptation is the Ghana Randomized Air Pollution and Health Study (GRAPHS). This study used fan-assisted efficient biomass-burning cooking stoves and liquefied petroleum gas (LPG) stoves to reduce the concentrations of carbon monoxide and $PM_{2.5}$ pollutants emitted into a dwelling from these types of stove and measured the health impacts on pregnant women (Chillrud *et al*., 2021). The group using LPG demonstrated a 47% reduction in mean 48-hour carbon monoxide exposure compared with the control. Mean $PM_{2.5}$ concentrations in the group using LPG were 32% lower than the control. The biomass stove did not significantly reduce carbon monoxide or $PM_{2.5}$. The post-intervention exposures still exceeded health relevant targets.

Well designed, implemented and monitored cooking-stove interventions can have positive effects. Although they may lead to a reduction in indoor air pollution, it is unlikely the levels will reach the WHO Ambient Air Quality Guidelines (WHO, 1987). However, improved air quality can reduce the adverse impacts, especially for vulnerable groups. One challenge remains: behavioural practices, culture and traditions, and even the taste of the food can affect the long-term feasibility and uptake of interventions by communities. Knowledge of the barriers and facilitators of all these factors is important for reducing domestic indoor air pollution in the long-term.

A transition from so-called 'dirty fuels' to cleaner, affordable options for cooking and heating requires support from all sectors to reduce mortality and morbidity from household air pollution in Africa. Alternatives include LPG stove tops and ovens, ceiling installation and solar cookers (Brown and Lankford, 2015; Goswami *et al*., 2019). Figure 3.11 illustrates the transition to clean fuel for cooking.



*Figure 3.11 Exposure of children to dirty fuels of coal-burning stoves and a clean LPG stove. Credit: A. Mathee (2010).*

#### 3.4.10.2 *Ambient air pollution*

The main pollutant of ambient air is particulate matter ($PM_{2.5}$), which is considered a major concern for Africa. Population growth and rapid urbanisation are expected to worsen air quality due to additional industrial, agricultural and anthropogenic activities that lower air quality. One of the major sources of ambient air pollution in Africa is the burning of fossil fuels for power generation. Fossil fuels are carbon-based compounds such as crude oil, bitumen, natural gas and coal which serve as sources of energy. Fossil fuels are important energy sources that play significant roles in the gross domestic products of almost all nations the world over (UNECA, 2011).

Africa is undergoing both an environmental and an epidemiological transition (NASAC, 2017). Household air pollution is the predominant form of air pollution, but it is declining, whereas ambient air pollution is increasing. Many African cities are facing rapid urbanisation, and areas with high traffic volumes coupled with high population densities are most at risk to levels of particulate matter that exceed the WHO Air Quality Guidelines (WHO, 1987). Ambient air pollution levels seem to be increasing in rapidly expanding sub-Saharan cities such as Ethiopia, Ghana and Rwanda (Fisher *et al.*, 2021). These levels of particulate matter are exacerbated by dust storms, biomass burning and industrial activities.

New technologies are being used to monitor the levels of ambient air pollution, alerting the citizens to take protective measures. One such example is the use of sensors and mobile applications in Arlit, the uranium city within the Sahara desert of Niger to monitor ambient air quality, especially in urban areas. This has the potential to bridge data gaps through crowdsourcing activities (e.g. citizen science initiatives for reducing exposure to urban air pollution, illustrated in Figure 3.12).

*The link between air pollution and climate change*. Climate change and air pollution influence each other, especially in the ambient environment (Brasseur, 2009; Rogelj, 2018). Activities that release air pollutants into the atmosphere can result in changes in the climate as many sources of air pollution (e.g. combustion of fossil fuels and biomass burning) are also sources of GHGs. Additionally, some pollutants also modify the climate directly as short-lived climate-forcing pollutants (IPCC 2014).

Africa has appreciable reserves of fossil fuels amounting to 9.5% of global crude oil reserves, 8% of natural gas reserves and 4% of coal reserves, according to British Petroleum (BP, 2012) and the African Development Bank (AfDB, 2011). BP estimated that more than 122 billion barrels of proven (established) oil reserves and almost 159 billion barrels of potential (promising) oil reserves lie beneath the surface of the African continent. It was also reported that the continent holds about 560 trillion barrels of proven reserves of natural gas and about 319 trillion barrels of potential natural gas reserves. Over-reliance on fossil fuels has contributed to several environmental and social problems in Africa. Some of these include depletion of the ozone layer, ocean acidification, depletion of non-renewable energy sources, global warming and air pollution.

The combustion of fossil fuels contributes both to GHG emissions and to air pollution emissions. Efforts to reduce GHG emissions through transitioning to cleaner forms of energy can present opportunities to simultaneously improve air quality and increase quality of lives. For example, $PM_{2.5}$-and ozone-related premature mortality and morbidity can be significantly reduced through policies that promote decarbonisation (Shindell *et al.*, 2012; Harmsen *et al.*, 2020). A changing climate can have wide-ranging effects on local air quality levels due to changes in emissions and meteorology (USEPA, 2011,d 2014; 25
European Respiratory Society, 2017; WHO, 2020). For example, emissions from power stations have been shown to increase during heatwaves, when more people use electricity for air conditioning (Kinney, 2008). A changing


*Figure 3.12 Screen shots of the Arlit mobile application on air pollutants and health*[9].

climate can also affect natural emissions such as biogenics, dust, biomass burning and pollen (Katelaris and Beggs, 2018).

Air quality is dependent on meteorology and is therefore sensitive to climate change (Jacob and Winner, 2009). Hotter and drier conditions increase wind-blown dust and can facilitate increased fires. In addition, changes in climate can affect the dilution or dispersion of air pollutants as well as their removal processes (e.g. by rainfall). Meteorological conditions and ambient temperatures also influence pollen and, to a certain extent, spore concentrations (Kinney, 2008). Because of climate change, mortalities related to air pollution exposure, especially tropospheric ozone ($O_3$) and $PM_{2.5}$, are expected to increase in many parts of the world; thus, it is important to consider current and future air quality when assessing the impacts of climate change on health (Orru, 2017).

In a changing climate with more extreme weather events, such as extreme rainfall or changing socio-economic situations, increased household-level burning activities may contribute to high indoor air (and outdoor) pollution levels. Warmer temperatures and increased occurrences of heatwaves could exacerbate the ill-health effects already present among people living in inadequate climate-proofed dwellings and with poor indoor air quality. Both extreme heat and air pollution are well-documented causes of human mortality and morbidity, and these two exposures combine to cause synergistic ill-health effects (Schnell and Prather, 2017; O'Lenick *et al.*, 2019) that will vary depending on the types of decarbonisation pathway that are adopted, and the suite of technology measures included. Since most African cities are at a relatively early stage of urbanisation, this gives us an opportunity to intervene now through green technologies to avoid the

[9] Arlit, the uranium city within the Sahara desert of Niger, showing $PM_{2.5}$, $PM_{10}$, ozone ($O_3$) and nitrogen dioxide ($NO_2$), wind speed, temperature, ultraviolet radiation level, humidity and health recommendations. https://africanarguments.org/2017/07/a-forgotten-community-the-little-town-in-niger-keeping-the-lights-on-in-france-uranium-arlit-areva/

economic, health and social consequences (Fischer *et al*., 2021).

#### *3.4.10.3 Volatile organic compounds*

*Current situation*. Volatile organic compounds (VOCs) are atmospheric contaminants that include benzene, toluene, ethyl benzene, xylene, etc. (see Table 6.1 in Appendix 2) They are mostly released into the environment through anthropogenic activities. They can travel a long distance from the point of production and enter the body by inhalation or through contact on the skin. This can lead to health problems such as asthma, neurological disorders and dermatitis; some are also carcinogenic to humans (IARC, 2017).

Africa has diverse sources of air pollutants ranging from biomass burning, traffic, industrial, power plant emissions and residential cooking, among others. Household fires used in cooking are a major source of VOCs worldwide, but especially in Africa (Andreae and Merlet, 2001). Most notably, the major sources of domestic energy in households in Africa are charcoal, agricultural wastes and wood (Wang and Hopke, 2013).

Traffic emissions are an important source of VOCs in Africa because of the type of internal combustion engine, its maintenance regimes, its age and its fuel consumption (Robert *et al*., 2007). Studies have shown that 73% of cars in Africa are older than 10 years (Kablan, 2010; Essoh, 2013). The age of these cars makes them highly polluting because of their inefficient combustion systems (Boughédaoui *et al*., 2009). Also, there is a significant difference in the quality of fuel and lubricants used in automobiles in Africa when compared with developed countries. A report by the UNEP shows that in emerging economies the average sulphur content of fuel used is high, reaching about 10,000 parts per million, while developed countries have significantly reduced sulphur content in their fuel, as low as 10 parts per million (UNEP, 2017). Inadequate waste management systems have also led some Africans to dispose of wastes using open burning systems (Wiedinmyer *et al*., 2014). Some new pollutants (such as hexabromocyclododecane and perfluorinated compounds) have also increased in the past 10 years (Holmström *et al*., 2005).

VOCs also affect indoor air quality, with emissions coming from different sources in the home, including paint, furniture polish, cleaners (soaps and laundry detergents), solvents and thinners, aerosol such as air fresheners, smokes from burning stoves or candles as well as cigarettes. The occurrence of VOCs has been reported although there are limited data on indoor VOCs in Africa. Portable electric power generators are gasoline or diesel-fuelled devices which provide short-time electrical power up to a certain wattage and are designed for outdoor use. Home occupants often place these generators near or in their homes because of potential generator theft and noise to neighbours (Ashmore and Dimitroulopoulou, 2009). In Nigeria, owing to the grossly inadequate supply of electrical power, there is a continuous increase in the use of portable electric power generators. The exposure to high concentrations of carbon monoxide in residential homes has resulted in several deaths in Nigeria where one study reported more than 60 people were affected in 2008 alone (Adefeso, 2020). This observation is supported by similar data from India demonstrating that the use of generators in urban areas increased the indoor concentration of carbon monoxide (Lawrence *et al*., 2004).

#### *3.4.10.4 Bush-forest fire*

Wildfires can impose a direct impact on human health under climate change, as they can simultaneously affect weather and the climate by releasing large quantities of carbon dioxide, carbon monoxide and fine particulate matter into the atmosphere. The resulting air pollution can cause a range of health issues, including respiratory and cardiovascular problems (WHO, 2017a).

*Current situation*. In recent decades, forest fires caused by human activities have increased (Cochrane and Laurance, 2002; Lewis *et al*., 2015). The current increase in forest fire is linked to climate change, especially with global warming and alarming global deforestation rate (FAO, 2012). Deforestation and forest fires act synergistically to reduce tropical rain forests (Cochrane and Laurance, 2002). Also, the recent surge in droughts and temperature relating to global climate change will lead to increased fires in the near future, especially in Africa (Abeli *et al*., 2014). Forest fires result in wanton deforestation, population size reduction, distortion of community structure and loss/migration of exotic species (Turner, 1996; Cochrane and Laurance, 2002; Laurance *et al*., 2012). Forest fires cause critical changes to soil properties, depending on the soil type, the quantity and quality of fuel, the time frame of the fire incidence and the temperature attained during the fire.

*Projections*. Gathering of reliable ground data in Africa is unachievable because of political reasons, technical and resource problems, and lack of proper statistical data. The pattern and frequency of forest fires prevented most African countries correctly registering annually the burned areas. Remote sensing is therefore the only means of collecting forest fire data in Africa. Some of the main causes of forest fires in Africa include natural causes, prescribed burning, negligence or lack of training and arson. No accurate estimates of the extent of damage done by forest fires in Africa are available. Unfortunately, ecologically and economically cogent resources are being increasingly destroyed by fires (Goldammer and Ronde, 2004).

Direct losses because of forest fires include loss of human life, disability and increased respiratory sicknesses due to heavy smoke, loss of housing and valuable possessions, loss of grazing, crops, livestock and subsistence natural resources, negative impacts on tourism and landmarks, reduced quality of water and enhanced soil erosion by water and wind. Forest fire emissions also have severe impacts on the atmosphere and have caused serious air pollution in Africa.

It is estimated that 42% of global biomass burned yearly is from Africa; this includes fire associated with deforestation. The fires release about 3,431 metric tonnes of carbon dioxide into the atmosphere and significant quantities of other emissions (Andreae and Merlet, 2001).

In Mediterranean countries, warmer temperatures and droughts have increased the recurrence of wildfires, exposing large populations to toxic emissions including particulate matter and other harmful compounds of smoke. Epidemiological studies indicate that exposure to wildfire smoke is responsible for respiratory morbidity associated with acute pulmonary and cardiovascular diseases (Watts *et al*., 2015, 2017). These pollutants add to the burden of respiratory diseases, as already discussed under air pollution in sections 3.4.10 to 3.4.10.3.

### 3.4.11 Specific recommendations for air pollution

1) Institutional policy
   (a) Institute policies for urban planning and to abate urban and indoor air pollution.
2) Health adaptation
   (a) Institute EWARS to anticipate the necessary surge capacity from air pollution.
   (b) Strengthen health systems to cope with surges in respiratory illnesses arising from air pollution.
   (c) Explore the use of sensors and mobile devices to alert communities to dangerous levels of air pollution.
   (d) Sensitise local communities and land developers against acts of bush burning.
3) Mitigation
   (a) Phase out the dependence on fossil fuels in major sectors to reduce emissions of GHGs, through partnerships with developed countries.
   (b) Institute real measurements of meteorological parameters and air pollution.
   (c) Explore the use of sensors and mobile applications to alert communities.

(d) Experiment with planting fire-resistant woods as forest guards to reduce forest fires.

4) Strengthening the evidence base
   (a) Undertake country-level surveillance of health impacts due to air pollution.
   (b) Estimate disease burdens at national levels.

## 3.5 Indirect impacts of climate change through societal changes

Climate change can have tertiary consequences when populations are demoralised and forced to relocate. Tertiary consequences include forced migration, economic dislocation, environmental decline, and conflict situations including traumatic, infectious, nutritional, psychological and other consequences or disruptions to health and social services. In this section we review the evidence for forced migration and conflict.

### 3.5.1 Forced migration and conflict

Migration is considered an adaptation strategy, and the nature of the response to migrants is often determined by the context of specific involved communities (Ebi *et al*., 2002.; Sobczak-Szelc and Fekih, 2020). In Africa, the causes of migration and movement of 'climate refugees' include economic, political (e.g. wars) and social factors as well as being partly or wholly affected by climate change. The five Sahel (G5) countries of Burkina Faso, Chad, Mali, Mauritania and Niger are experiencing some of the worst climate change impacts including increased temperatures, more frequent droughts, prolonged heatwaves, soil degradation, increased flooding, reduced agricultural productivity increasing heat, sea-level rise, land degradation, extreme weather events and exacerbation of food and water security issues (Brown, 2011; Mbiyozo, 2020). They also face rapid population growth, poverty, violent extremism, organised crime, poor governance and weak institutions; all these factors are influenced by the effects of climate change. Hence, the Sahel is likely to continue to be a major region of concern in terms of migration and a contributing factor for this relates to food insecurity due to drought (WHO, 2003, 2012).

Regions dependent on rain-fed agricultural practices are especially sensitive to civil conflict after droughts, and rising food costs alongside food scarcity leading to violence. Another important conflict concern in the Sahel is shifting migration routes of herders who seek grazing land to avoid livestock losses. A concern is the potential high exposure to zoonoses, and problems caused by climate change that increase the climate change-related health risks for these herding groups who seldom receive health system services (Montavon *et al*., 2013). 26

*Current situation*. Climate change is a 'risk multiplier' that exacerbates migration and conflict in regions where poverty and social insecurity, among other drivers, prevail (Scheffran *et al*., 2019). These environmental drivers are exacerbated by economic, social, political and demographic ones that act independently or in combination. People may migrate temporarily or permanently within their country or across geographic borders. For example, in 2008, floods in Mozambique displaced 90,000 people who have since made temporary mass displacement sites their permanent homes (NRC and IDMC, 2015). In the Ethiopian Highlands, drought heightened migration of men away from rural areas to urban areas in search of work (Gray and Mueller, 2012).

A meta-analysis of country-level studies on environmental change and migration showed that climate change and ecological hazards are key drivers of migration in sub-Saharan Africa (Hoffmann *et al*., 2020). Within-country displacement is a concern, as shown in Figure 3.12, probably caused by environmental stressors affecting livelihoods and leading to urbanisation, with Ethiopia experiencing most displacement and Mali the least.

*Projections*. Assessments of future trends of migration and conflict in Africa from climate change give contradictory results due to the complexity of the interrelated factors

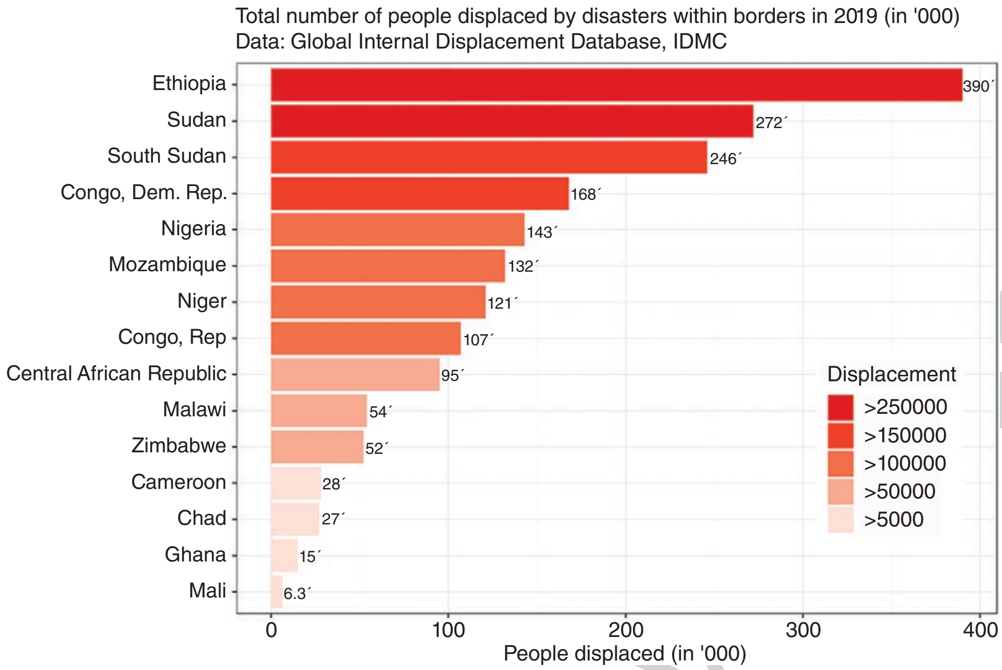



*Figure 3.13 Disaster displacement in sub-Saharan Africa.*

(Ebi *et al*., 2002). The World Bank recently suggested that if action is not taken by 2050, there will be more than 86 million internal climate migrants in sub-Saharan Africa (Rigaud *et al*., 2018). Migration will occur as competition for freshwater and arable land intensifies and may increase the probability of violent conflicts related to climate change (Scheffran *et al*., 2019). Whether such stresses will lead to violent outbreaks depends on many country-specific socio-political, economic and cultural factors (Ebi *et al*., 2002); how these stresses will lead to impacts on human health must be better researched and understood.

*Recommendations*. All nation states require migrant policies to protect climate migrants facing climate change-induced migration. Southern Africa, for example, is somewhat lagging in this regard. The UN–AU partnership is one possible platform for joint and effective partnership in building migrant policy in Africa (Olutola, 2020). Climate change projections also need to be more strongly integrated in migration scenarios: the need for data and research on migration dynamics is key to improving policy-making.

### 3.5.2 Mental health and post-traumatic disorders

Many climatic hazards such as severe droughts, floods and storms cause people to lose their jobs, property and loved ones, and they may be forced to migrate in this demoralised state. In such circumstances, climate change impacts the mental health of the bereaved and displaced person who experiences post-traumatic disorders because of the loss. Mental health can be direct or indirect, acute or chronic. Direct, acute events result from exposure to extreme weather, for example an intense tropical cyclone resulting in loss of family, livelihoods, dwellings, etc. The direct impacts can encompass disorders such as post-traumatic stress and have lifelong consequences.

Exposure to high temperature, whether it is acute exposure to heatwave or chronic (by steadily increasing temperature), can lead to traumatic stress as well as physiological impacts. Physiological effects on the brain may influence emotions, aggression and violence; and, secondly, high temperatures can affect crop yields and livelihood stability. Such economic shocks can lead to mental health

**Case Study 7  Criminal activity**

*Background*. Several studies have shown the combined impacts of temperature and relative humidity on crime rates. A recent study in Tangshan, China, showed that at the end of the 21st century the rates of rape (violent crime) and property crime in Tangshan will increase by 9.5 ± 5.3% and 2.6 ± 2.1%, respectively (Hu *et al*., 2017). Similarly, a study in USA also showed that temperature rise is positively correlated with criminal behaviour. According to the study, between 2010 and 2099, climate change will cause 22,000 murders, 180,000 cases of rape, 1.2 million aggravated assaults, 2.3 million simple assaults, 260,000 robberies, 1.3 million burglaries, 2.2 million cases of larceny and 580,000 cases of vehicle theft (Ranson, 2014).

Similarly, in Nigeria, the movement of herdsmen in search of pasture and their resultant clashes with farmers and host communities in recent times has aggravated insecurity in the country, especially in the north-central region and invariably in other parts of the country. The main crux of these clashes is the demand for available resources, especially grazing land which is depleting because of farmland extension due to decreases in food productivity, resulting from climate change. Farmers often accuse herders, mostly from the Fulani ethnic group, of allowing their cows to destroy their crops. Herders, in turn, grumble over the loss of their livestock to militias as well as gangs from local communities who attack them, triggering blood-chilling reprisals. These criminal activities are the direct effect of climate change because of loss of grazing land in the northern part of the country owing to drought and high temperature in this region. Table 3.3 shows the upsurge in criminal activities in flooded areas in Nigeria in three consecutive years; the data in the table show that the year with the highest level of flooding (2012) recorded the highest number of criminal cases. There is a need for further studies to establish the direct relationship between crime and climate change; nevertheless, flooding triggered loss of livelihood in the affected areas owing to the destruction of farmlands and business, houses were destroyed, and companies lost their machinery, which in turn created people who were jobless and thereafter took to crime.

**Table 3.3  Crime records in flood-affected areas for 2011, 2012 and 2013**[10]

| | Year | | |
|---|---|---|---|
| **Offences** | **2011** | **2012** | **2013** |
| Murder | 126 | 239 | 39 |
| Robbery | 223 | 191 | 43 |
| Grievous harm and wounding | 200 | 340 | 163 |
| Assaults | 342 | 425 | 123 |
| Rape and indecent assaults | 6 | 8 | 5 |
| Theft and other stealing | 109 | 116 | 142 |
| Burglary | 40 | 44 | 17 |
| House breaking | 289 | 287 | 51 |
| Store breaking | 191 | 285 | 1 |
| False pretence and cheating | 347 | 444 | 33 |
| Offence against liquor acts | 4 | 6 | 4 |
| Unlawful possession | 78 | 99 | 66 |

*Lessons learnt from this case study*. This study illustrates that temperature rise can indirectly cause forced migration and mental stress, leading to societal disruption. Mitigation measures to limit uncontrolled open grazing that is still practised in some developing economies where farmlands are destroyed should be discouraged, and replaced with ranching systems. This will eliminate farmers' and herders' clashes and lead to the attendant better management of herds with increased profit margins. Public recreation centres with installed cooling systems should be provided in communities to aid relaxation, thereby reducing incidences of criminal activity because of increased temperature and stress linked to climate change.

impacts (Burke *et al*., 2015). Vulnerability to these mental health effects is exacerbated by several factors including age, pregnancy, geographical location, pre-existing medical and mental conditions as well as socio-economic inequalities (Rother *et al*., 2020). Other emerging climate change mental disorders are eco-anxiety, eco-guilt and ecological grief, among others (Cianconi *et al*., 2020). Case Study 7 illustrates the ramifications of heat, and that forced migration can lead to societal upheaval and resorting to criminal activities.

*Current situation*. Both direct (e.g. storms, wildfires, heatwaves) and indirect (e.g. sea-level rise and migration) effects of climate change can affect mental health. Such impacts include depression and anxiety, post-traumatic

[10] Source: Benue State Police Command (2016).

stress disorder and suicide, which may result from displacement, loss of family members in extreme weather events, disabling injuries, lost livelihoods (for example through long-term drying in rural regions) and impoverishment (Obradovich *et al*., 2018). Substance (especially alcohol) misuse and abuse are also more prevalent among displaced populations and those subject to extreme environmental stressors. These linkages are not clear but seem to be accelerating, disproportionately affecting marginalised people.

Post-traumatic stress disorder caused by extreme weather events impacts, such as floods and fires, among people living in urban informal settlements has been increasing in sub-Saharan Africa (Hayes *et al*., 2018). Other chronic effects include higher rates of aggression, violence and gender-based violence in relation to increased temperatures. In South Africa, rates of gender-based violence in the country are among the highest in the world, affecting 1 in 3 women during their lifetime. It will be important to investigate whether these rates rise even further after extreme weather events in the country, as has been reported elsewhere (Neumayer and Plümper, 2007; Chersich *et al*., 2019).

*Projections*. In Africa, increased immigration and refugee pressures on the environment and on neighbouring countries is anticipated. The demographic disruption and associated social tension may result in increased interpersonal violence and crime. In addition, damaged transport infrastructure and poor weather conditions or increased temperature may increase the incidence and severity of motor vehicle-related crashes, as has been seen among male drivers (see Wyon *et al*., 1996; Nofal and Saeed, 1997).

The WHO predicts that, by 2030, in an increasingly uncertain world, depression will be the most widespread health problem on the planet, in the top three of all-cause morbidity, in all continents (WHO, 2016). While this situation not only emanates from climate change, it certainly plays a contributing role.

#### 3.5.3 Specific recommendations for forced migration and mental health

1) Institutional policy
   (a) Institute policies for creating green spaces in cities to promote mental health.
2) Health adaptation
   (a) Institute EWARS to anticipate the necessary surge capacity due to migration and post disaster traumas.
   (b) Strengthen health systems to support the mental health, trauma and depression of vulnerable groups of migrants and victims of disasters.
3) Mitigation
   (a) Institute measures to limit conditions leading to migration and conflicts.
4) Strengthen the evidence base.
   (a) Undertake country-level surveillance of the health impacts of migration.

# AUTHOR QUERY FORM

Dear Author,

During the preparation of your manuscript for publication, the questions listed below have arisen. Please attend to these matters and return this form with your proof.

Many thanks for your assistance.

| Query | References Query | Remarks |
| --- | --- | --- |
| 1 | AUTHOR: "Mkonda, 2019" has not been included in the Reference List, please supply full publication details. | |
| 2 | AUTHOR: "EASAC, 2019" has not been included in the Reference List, please supply full publication details. | |
| 3 | AUTHOR: "ACPC, 2017" has not been included in the Reference List, please supply full publication details. | |
| 4 | AUTHOR: "Médéou, 2015" has not been included in the Reference List, please supply full publication details. | |

# 4 How can adaptation and mitigation options protect human health in Africa?

## 4.1 What are the existing regional risks from climate change in Africa?

### 4.1.1 Northern Africa

The Northern African region is projected to be subject to warming above the global average and could increase by up to 8 °C in the Sahel region (IPCC, 2007; World Bank, 2013; IPCC, 2021). Precipitation could decline by 40–60% during the summer months of the Northern Hemisphere, leading to increased risk of droughts and water shortages (Prudhomme *et al.*, 2014). The drought conditions will be detrimental to the agriculture sector and food security in the region since the growing season for crops will be shortened significantly. However, areas south of the 25° S are projected to see increases in precipitation (World Bank, 2013). Salinisation of groundwater due to water extraction and projected sea-level rise are other threats to human health and well-being in the region, particularly in deltaic areas (World Bank, 2013). Extreme heat and inadequate access to drinking water compounds the health risk as such conditions are associated with diarrhoeal diseases, heat-related stroke as well as declining labour productivity for people working outdoors, as already elaborated in the previous sections (Smith *et al.*, 2014).

### 4.1.2 Eastern Africa

Eastern Africa shows varied geography, topology and climates (Haile *et al.*, 2020). In both the equatorial and tropical latitudes, the mean temperature across the region has increased by 1–3 °C over the past 50 years, allowing malaria-carrying mosquitoes to survive at higher altitudes (UNFCCC, 2020). The complex topography ranges from the Great East African Rift Valley, the mountains such as Kilimanjaro, Kenya, Meru, Elgon and Ethiopian Highlands, to the Danakil depression which has the hottest area on Earth with temperatures of over 60 °C. Fragile, traditional, rain-fed subsistence agriculture with livestock production accounts for 30% and crop farming 70% of the agricultural sector. The increasing frequency of drought events in Djibouti, Ethiopia, Kenya and Somalia undermines the health and livelihoods of farmers, agro- pastoralists and pastoralists in the region (FAO, 2005; UNECA, 2011; EM-DAT, 2020). Environmental degradation through deforestation, intensification of agriculture in the arid and semi-arid lands, rapid rates of urbanisation and industrialisation are all driven by a rapid population increase which stood at 330 million people in 2015, of whom 80% lived in the semi-arid parts of the region. Case Study 1 illustrates the dramatic effect of heat rise on melting the centuries-old ice caps on the Kilimanjaro mountains; and Case Study 5 highlights the complex interaction between heat and pest infestations on the livelihood of farmers.

### 4.1.3 Central Africa

The Central Africa region is dominated by the Congo basin. With respect to observed long-term temperature changes in the region, the few available station data suggest a statistically significant warming (IPCC, 2007), with an increase in warm extremes (example warmest days increased by about 0.25 °C per decade) and a decrease in the occurrence of cold spells (Aguilar, 2009). An assessment of several modelling studies confirms that it is unlikely that drastic changes in annual total rainfall will occur in the future over the greater Congo basin. These projected variations in rainfall and temperature will result in substantial change in the hydrology and increase flood risk in low lying and coastal areas. The 6th IPCC report (IPCC, 2021) projected increases in heavy precipitation and pluvial flooding, and increases in river flooding. This will amplify the direct and indirect health impacts associated with floods, as illustrated in section 3.3.2.

### 4.1.4 Western Africa

The World Bank (2013) highlights those arid areas that are expected to expand in Western Africa, and the incidence of drought is expected to increase during the 21st century (IPCC, 2007). A robust long-term decline in agricultural yield of greater than 15% by 2100 is projected for the equatorial fully humid climate zone, which includes Guinea and regions of Western Africa, Central Africa and most parts of Eastern Africa (World Bank, 2013). In certain parts of the region, the decline in rain-fed agriculture could be as high as 50% (Madzwamuse, 2010). The water level of Lake Chad is dropping due to decreased rainfall in the catchment area and misuse of anthropogenic agents. Climate change will result in extreme weather and climate events such as droughts and floods, but it will also aggravate water stress and water scarcity (Cheung, 2010) as well as ecosystem changes and biodiversity losses.

A distinctive feature of Western Africa is the approximately 15,000-kilometre-long coastline. Coastal towns in this region are some of the most developed of Africa's urban areas. Sea-level rise is likely to have a significant impact on these hubs, with expected coastal degradation having further impacts on fisheries, food security and tourism (Madzwamuse, 2010). On a more positive note, results from the 'Mapping Malaria Risk in Africa' project (MARA/ARMA) indicate that, by 2050 and onwards, a large part of the western Sahel and much of southern Central Africa will probably become unsuitable for malaria transmission (Thomas, 2004).

### 4.1.5 Southern Africa

Surface temperatures in Africa are projected to increase by 4–6ºC over the subtropics and by 3–5 °C over the tropics due to climate change (Engelbrecht *et al.*, 2015). At a temperature increase of 2 °C, Southern Africa is projected to experience a 20% reduction in precipitation with more consecutive dry days in Namibia, Botswana, northern Zimbabwe and southern Zambia, and a 5–10% reduction in the volume of the Zambezi basin.

Regional climate models show that minimum and maximum temperatures and the number of heatwave days will increase significantly across the continent (Asefi-Najafabady *et al.*, 2018; Sylla *et al.*, 2018; Weber *et al.*, 2018). A reduction in precipitation is predicted over parts of Northern Africa and the southwestern parts of South Africa (Ebi *et al.*, 2014). However, increased and extreme rainfall is expected in regions characterised by high or complex topography. Although Africa is the world's lowest contributor of GHGs, which are the dominant drivers of climate change, it is among one of the continents that is most vulnerable to the effects of climate change because of its high exposure and low adaptive capacity (Ebi *et al.*, 2002; Osman-Elasha, 2009; Butler, 2016).

### 4.1.6 Small Island Developing Island States

The African Small Island Developing States (SIDS) comprise Cabo Verde, the Comoros, Guinea-Bissau, Mauritius, Sao Tome and Principe, and the Seychelles. The Fifth Assessment Report of the IPCC emphasised that SIDS will continue to be threatened in the 21st century by rising sea levels, tropical and extra-tropical cyclones, rising air and sea surface temperatures and changing rainfall patterns (IPCC, 2018). Because of the low elevation of many island coastlines and atolls, rising sea levels are considered the most significant threat to those states. Furthermore, in addition to irreversible and life-threatening climate-induced change, many SIDS also face challenges related to dwindling resources and limited income-generating opportunities for their citizens (Brown, 2011). While considerable attention has been given to the biophysical impact of climate change on SIDS, there has not been sufficient focus on how climate change could exacerbate social vulnerability. The local communities are already adapting to climate change, but institutional support will prove crucial to ensure that adaptation strategies are appropriately structured, organised and result in successful outcomes.

SIDS face particular challenges related to their size and relative geographical isolation. Those challenges complicate efforts to promote economic development while safeguarding those countries' integrity. In particular, the remoteness and small size of African SIDS makes it difficult for them to achieve economies of scale and reap the benefits of global commodity chains. Understanding, anticipating and adapting to economic, social, environmental and climate-related challenges is therefore of critical importance if those states are to achieve economic stability and security. Governments will therefore be largely responsible for implementing most adaptation strategies and decisions, which will require significant financial support. Mobilising resources for major climate change initiatives will necessitate effective coordination at national, regional and international levels to leverage support for individual SIDS. Campaigns raising international awareness can also bolster domestic support for climate change initiatives and ensure that the states are ready to respond to climate risks and can capitalise on emerging opportunities.

### 4.1.7 Summary of vulnerability across the African regions

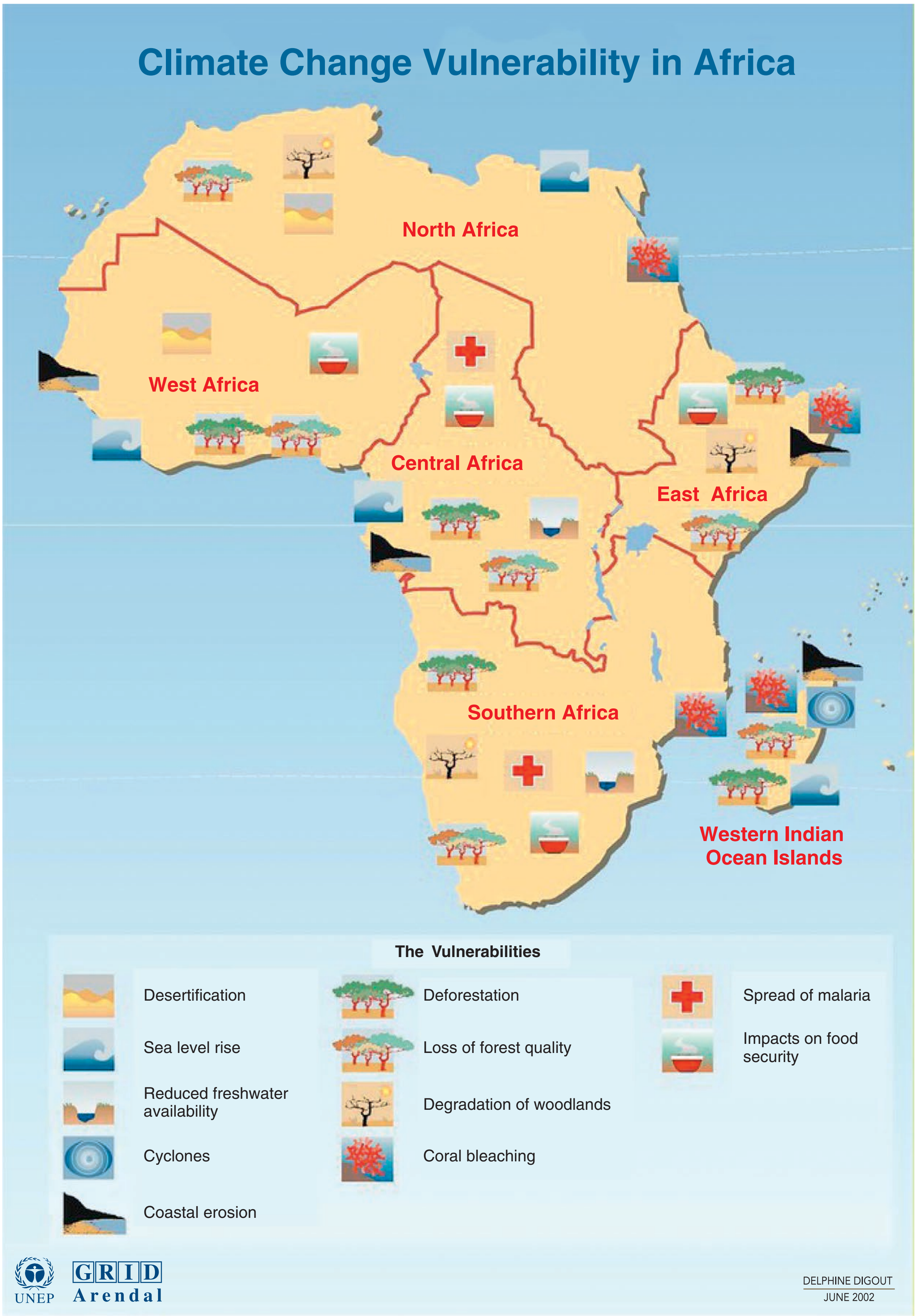
Africa is considered one of the most vulnerable continents to climate change and climate variability (Ebi *et al*., 2014). This situation is aggravated by multiple stressors that occur at different levels, thereby affecting Africa's strong economic dependency on climate-related activities and products, in the context of low adaptive capacity. While all of Africa's inhabitants are exposed, some population groups are more vulnerable than others. In terms of climate change vulnerability, vulnerable groups include women, especially pregnant women; unborn children, neonates and children younger than 5 years; the elderly; people living in poverty; outdoor labourers; people with pre-existing diseases, especially HIV/AIDS; urban dwellers; migrants; and marginalised groups (van Wesenbeeck *et al*., 2016).

*Projection*. Projections are scarce and complex for how the health of vulnerable groups will be affected by climate change. Almost all African countries are vulnerable to the impacts of climate change, and it is those living in poverty, among other vulnerable groups, who will be worst affected. Basic needs such as water availability will be affected by climate change; this in addition to growing populations and patterns of water use that suggest African countries will exceed their economically usable, land-based water resources by 2025 (ClimDev-Africa, 2013). The vulnerability of the region has been worsened by the lack of strong institutions to deal with calamities and environmental disasters caused by climate change episodes (Mkonda, 2019; Msafiri, 2019).

In summary, climate change will affect different parts of Africa in different ways. The vulnerable regions, identified by the IPCC Assessment Report 5th and 6th Assessment Reports (IPCC, 2014, 2021), are shown in Figure 4.1.

### 4.1.8 Specific recommendations for existing climatic vulnerabilities in Africa

1. Map the vulnerable regions
   (a) Undertake risk zone mapping for the regions in terms of geography and climate.
2. Conduct vulnerability and needs assessments of each region and country
   (a) Characterise the social determinants of vulnerable populations.
   (b) Assess how and under what circumstances vulnerable groups are exposed to climatic hazards.
   (c) Identify the health needs of vulnerable groups.
3. Implement a unified approach to reducing the vulnerabilities
   (a) Protect exposed populations for immediate relief from adverse health effects of climate change.




Sources: Anna Ballance, 2002.

*Figure 4.1 The main vulnerable regions of Africa.*

(b) Institute long-term measures to mitigate the emission of GHGs in key sectors.

## 4.2 Have we reached tipping points in our existential risks? Mapping the future

Mapping the future requires making projections based on existing information. The preceding sections have demonstrated that the risk of climate change is real in Africa. However, most of Africa lacks sufficient country-specific data to draw conclusions about future trends. Nonetheless, certain projections of tipping points can be made for existential risks. The global and African evidence on climate change and health is compelling that it has reached a tipping point if adaptation and mitigation are not instituted now. Catastrophic tipping may arise by exacerbation of the situation through the interaction of multiple factors including a lack of a regional strategy or lack of preparedness by national authorities. Climate change tipping points for Africa have been elaborated in the preceding sections and corroborate the IPCC's Fifth and Sixth Assessment Reports (IPCC, 2014, 2021) and include the following:

- Heavy rainfall, heatwaves and drought will have a disastrous impact across the Sahara and parts of West, East and Southern Africa. Cholera is primarily associated with weather and climate variability, suggesting possible changes in incidence and geographical range with climate change. Several studies highlight that cholera is associated with heavy rainfall in coastal West African countries and South Africa. In Eastern Africa, an increase in temperature or rainfall was observed to escalate the number of cholera cases. There are projected increases in precipitation in areas of Africa, for example West Africa where cholera is already endemic. This will possibly lead to more frequent cholera outbreaks in the sub-regions (Niang *et al.*, 2014).
- Temperature rise will directly or indirectly negatively affect food security through the farming of cereal, non-cereal and perennial crops as well as livestock (IPCC, 2014). Of particular concern to the continent is the tipping points that impact food security. The impact of climate change will increase the risks of food insecurity and the breakdown of the food system. Economically, many Africans depend for food, fibre and income on primary agricultural and fisheries sectors that are affected by rising temperatures, rising sea levels and erratic rainfalls. Africa's food production systems are among the world's most vulnerable because of their extensive reliance on rain-fed crop production, high intra- and inter-seasonal climate variability, recurrent droughts and floods that affect both crops and livestock, and persistent poverty that limits the capacity to adapt (Boko *et al.*, 2007). The following sectors will be affected:
- *Cereal crops*. Climate change is very likely to lower yields of major cereal crops across Africa, although the degree to which yields will fall will vary significantly across regions. In the dryland areas of Eastern Africa, yields of wheat, sorghum and millet will fall by 2050. This will be influenced by the melting of ice caps in the Kilimanjaro mountains and its negative effects will be greater in savannah ecosystems where it will affect improved crop varieties more than traditional varieties. In the Sahel, projections indicate millet yields will fall significantly under various scenarios.
- *Non-cereal crops*. Changes in climate will have a variable impact on non-cereal crops; both losses and gains in productivity are possible. Across sub-Saharan Africa, bean yields will fall significantly with 5 °C warming. In Eastern Africa, projections indicate bean yields will decrease by mid-century. In West Africa and the lowland areas of East Africa, banana and plantain productivity could fall.
- *Perennial crops*. Projections indicate that agro-climatic zones suited to economically important perennial crops will shrink significantly, largely because of rising temperatures. Under high-emissions

scenarios, agro-climatic zones that are now very good for perennial crops may become marginal. Zones that are now marginal may become unsuitable by 2050. West Africa may also become less suitable for cotton and more suitable for cashew.

- *Livestock*. Climate change could have an adverse effect on livestock production in Africa. Rising temperatures and changes in precipitation will bring more heat and water stress and shift the distribution of pests and diseases. These changes will have adverse effects on pastoral livelihoods and rural poverty.
  Projections indicate that Northern and Southern Africa will become drier with climate change, a particular concern for livestock production. Scarcity of water will have both direct and indirect effects on livestock production. In Botswana, for example, drier and warmer conditions by 2050 could raise the cost of pumping drinking water for livestock from boreholes by as much as 23%. Scarcity of water will indirectly affect livestock because production of feed crops will fall. In East Africa, the availability of maize leaves and stems for feeding cattle could decrease by 2050.
- Another tipping point of concern is the incidence in vector- and water-borne diseases associated with climatic changes in mean temperature and precipitation, leading to changes in the geographical ranges of vectors. The additional health effects attributable to climate change create a pressure on the already weak and overburdened African health system to respond effectively.

## 4.3 How will developing pathways influence future scenarios?

Climate change and sustainable development are inextricably linked to socio-economic development, social impacts and health effects. Managing the health effects of climate change requires a resilient health system that can anticipate and cope with the additional disease burden. This situation will put pressure on the African health system which varies across the continent in infrastructure, labour force and delivery of services. A partly or inadequately functioning health system will undermine the health of the African population and reduce the likelihood of attaining SDG 3, namely good health and well-being. Food insecurity will affect SDG 2, zero hunger, while water scarcity and contamination will affect SDG 6, clean water and sanitation. Global temperature rise will exacerbate the levels and prevalence of communicable and non-communicable diseases in Africa including cardiovascular diseases, chronic respiratory diseases, diabetes, cancers, malnutrition and disaster-related injuries and deaths. Therefore, climate scientists from the WHO and other United Nations organisations need to enforce the SDG 13 on climate action, SDG 3 on health, and SDG 16 on peace, justice and strong institutions. The United Nations should provide leadership and the evidence base for international action on surveillance, prevention and control of communicable and non-communicable diseases, including other health conditions that arise because of climate change, which is not entirely caused by human activities on the continent.

Health is tied to economic development pathways; a healthy nation is an economically productive one, and an economically productive nation is a healthy one. Climate change will have far-reaching economic consequences. For example, modelling scenarios for Tanzania, where agriculture accounts for about half of gross domestic product and employs about 80% of the labour force, indicate that changes in climate could increase poverty and vulnerability. Similarly, scenarios for Namibia indicate that annual losses to the economy associated with the impacts of climate change on the country's natural resources could range between 1% and 4.8% of gross domestic product. Ghana's economy and agricultural sector are particularly vulnerable because cocoa is the single most important export product and it will be affected by changes in climate. Cocoa

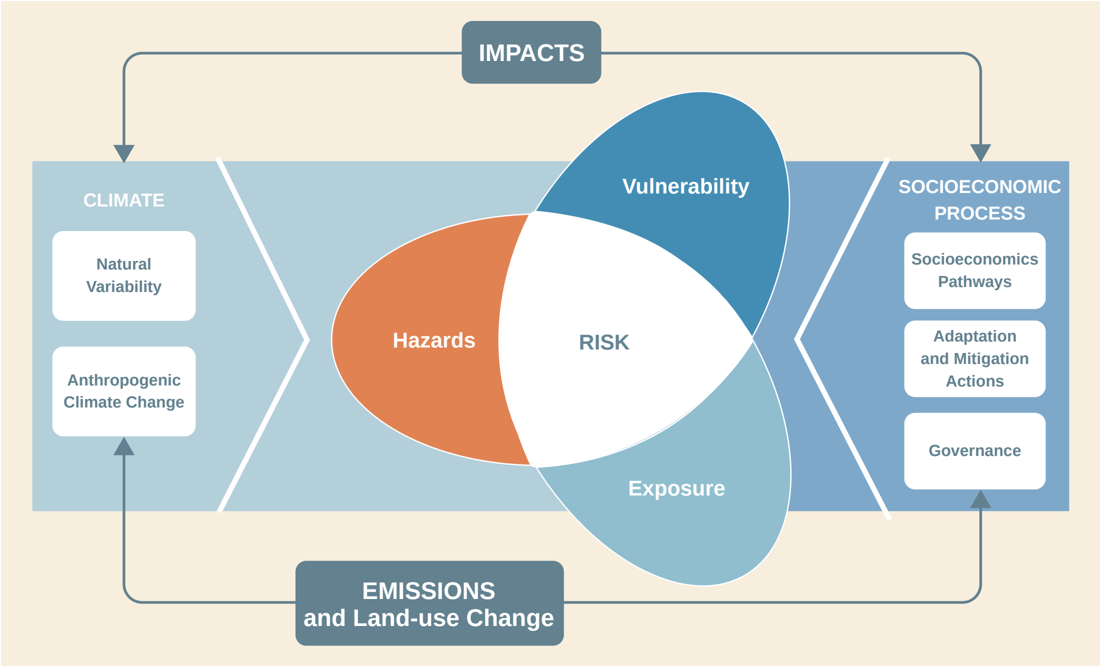



*Figure 4.2 The linkage between vulnerability and adaptation and mitigation*[1].

production is thus central in debates on development and poverty alleviation (IPCC, 2014, 2021).

## 4.4 What approaches do we have for adaptation and mitigation?

Risks related to climate change are the endgame of the interaction between climate-related hazards and the vulnerability of exposed societies, communities and systems in terms of livelihoods, infrastructure, ecosystem services and governance (WHO, 2013). The combination of existing regional risks to climate change and the dire projected impacts on development are compelling evidence for a call to action. Such actions are adaptation and mitigation. Adaptative strategies build resilience to climate change in the short term, and mitigation strategies reduce long-term carbon and methane emissions (IPCC, 2014). Figure 4.2 shows the linkage between adaptation and mitigation and how the risks of adverse health impacts to climatic hazards depend on the degree to which a vulnerable population is exposed to specific hazards.

### 4.4.1 Adaptation for immediate health protection

To manage the inevitable impacts of climate change, Africa needs to adapt to the multiple climatic hazards already elaborated in chapter 2. Adaptation will lessen the health risk of infectious diseases, respiratory diseases, cardiovascular and non-communicable diseases including heat-related illnesses, mental illness and criminal activities, injuries, undernutrition, allergies and poisoning. Since these adverse health effects are also associated with losses in productivity, livelihoods, income, jobs and properties, and socio-economic hardships widening the existing social inequity gaps of affected groups, adaptation will also reduce these risks. The goals of adaptation are to reduce exposure to climatic hazards, reduce vulnerability and build capacity for responding to and managing adverse health effects. Adaptation consists of taking actions to support individuals, communities and the environment to adjust to the effects of climate change that cannot be avoided. It delivers immediate benefits at national and local

[1] IPCC (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summary for Policymakers* (Figure TS.1, p.60).

levels. It is imperative to adopt the following approaches for adaptation:

- *Disaster risk reduction, to anticipate, manage and reduce the health impacts*
    - Mapping and monitoring of climatic hazards, vulnerability and health consequences.
    - Formulating and implementing policy and programmes through national plans incorporating health in NAPs.
    - Implementing early-warning systems.
        - For heatwaves, floods, epidemics and infectious diseases including vector-, food- and water-borne diseases and major NCDs.
    - Training of relevant health staff in recognising and managing climate-sensitive diseases.
        - To anticipate and manage surge capacities.
        - To support communities to reduce their vulnerability to adverse health effects of climate change.
    - Structural and environmental modifications to manage development in flood-prone and high-risk areas, and to manage storm and wastewater.
    - Engaging in broader collaboration with other sectors.
        - Promoting Health Impact Assessment as a tool for the above goals under the umbrella of Health in All Policies (HiAP).
- *Social and behavioural modification*
    - Understand the beliefs and practices of local populations to raise their awareness for building capacity in livelihoods and security adaptations, such as the following:
        - Changing cropping patterns, livestock, and agricultural practices.
        - Applying new technology options based on traditional and local knowledge including cooking with biogas.
        - Providing education and awareness of pollution, the importance of hygiene, drinking boiled water, improving peoples' awareness of vector-borne diseases, etc.
- *Institutional support*
    - In formulating and passing laws, regulations and guidelines based on solid evidence about climate change and health to support disaster risk reduction and the other components listed above.
    - These include national and regional adaptation plans including mainstreaming; sub-national and local adaptation plans; water management programmes; disaster planning and preparedness; integrated water resource management; community-based adaptation.

### 4.4.2 Mitigation for immediate and long-term health protection

The inherent limits to adaptation, including physical, behavioural, technological and financial ones, warrant the need for mitigation strategies to reduce long-term effects and must be started now (EASAC, 2019). The 2
impacts of mitigation will be felt more at regional and global levels. Mitigation focuses on addressing causes of climate change by reducing and eliminating GHG emissions at source. However, both adaptation and mitigation are needed as both deliver health benefits over different time frames (IPCC, 2014). Unmitigated effects of climate change will result in a disastrous situation in health and other sectors. It is pertinent to include adaptation and mitigation in the wider context of managing adverse health effects. Curbing GHG emissions to maintain the global temperature increase below 2 °C requires immediate actions now and can be implemented at the community level by actions such as the following:

- Formulate and implement mitigation strategies.
- Limit the emission of GHGs by forging partnerships with developed countries.
    - Implement green technologies in key sectors including transport, agriculture

and energy to reap health co-benefits for whole communities.

- Develop climate change strategies and action plans. Some model examples include the following:
  - Ethiopia's Programme of Adaptation to Climate Change covers sectoral, regional, national and local community issues.
  - Mali integrates adaptation into many sectors.
  - Mainstreaming initiatives, such as the 20-country Africa Adaptation Programme, launched in 2008, foster cross-sectoral adaptation planning and risk management (UNDP, 2015).
  - National climate-resilient development strategies include Rwanda's National Strategy on Climate Change and Low Carbon Development. Niger, Zambia and Mozambique are involved in the Pilot Program for Climate Resilience.
  - Zambia's Sixth National Development Plan 2011–2015 and the new Economic and Social Investment Plan in Niger reflect some integration of climate-resilience measures in national development plans.
  - Intersectoral approaches to climate risk management are emerging in integrated water resources management, integrated coastal zone management, disaster risk reduction and land use planning. In South Africa, design principles for climate change have been incorporated into existing biodiversity planning to guide land use.
  - In some African countries, the commitment to climate adaptation is reflected in broader policy frameworks, such as Namibia's National Policy on Climate Change and Zambia's National Climate Change Response Strategy and Policy.
  - South Africa's National Climate Change Response Policy White Paper. Lesotho's coordinated policy framework involves all ministries and stakeholders. Ten countries were developing new climate change laws or formal policies.
  - In 2012, Gabon proposed a National Coastal Adaptation Law, controlling deforestation and forest degradation, and reducing agricultural waste.
- Improve farming technology in the forestry and agricultural sectors.
  - According to the IPCC (2014) report, 20% of global GHG emissions can be controlled by forest clearing, controlled logging, and fire and infrastructure development.
- Similar actions in other sectors will also lead to co-benefits (for instance, see examples in Figure 4.3).

#### *4.4.2.1 What are the co-benefits of mitigation measures?*

Reduction of GHGs will slow down climate change and its adverse health consequences. Hence, when properly done, mitigation measures will also have health benefits in the long term, starting from global and regional levels right down to the community level. For instance, health expenditure linked to climate change often arises as an unintended but harmful policy or programme in non-health sectors such as transport, urbanisation, agriculture, etc. Hence, mitigating the impacts of climate change in non-health sectors will have co-benefits in reducing costs associated with health care, increases in productivity, and contribute to the social and political stability of a country.

Some major co-benefits of mitigation in the transport, agriculture, urban development, energy and sanitation areas are illustrated in Figure 4.3 (UNEP, 2020a). For instance, introducing clean fuels in the transport sector and using alternative commuting modes not only mitigate against climate change but also reduce the health risk of many NCDs, such as obesity, diabetes, heart disease and cancer, which are in part related to physical inactivity. Similarly, switching from coal to wind power can both reduce climate change and simultaneously save lives endangered by air pollution. Another example is modifying farming practices to reduce carbon emissions with a concomitant reduction in health risks.

| | Environmental Benefits | Health Benefits | Economic Benefits |
|---|---|---|---|
| **Transport** Tight standards to reduce sulphur in fuels | Reduction in acid rain phenomena, thus lesser forest and crop damages, and lesser acidification of soils | Reduced incidence of diseases such as cardiovascular and respiratory, cancer and adverse reproductive outcomes | As a comparison, eliminating lead in gasoline on a global scale have been estimated at approximately 4% of global GDP. |
| **Agriculture** Integrated landscape management | Conservation of biodiversity and critical ecosystem services, hydropower generation, improved water quality and quantity | Reduced incidence of diseases associated with poor water quality (e.g. diarrhoeal, etc.) and/or with poor personal hygiene | Reduced health costs from water related diseases. Reduced water and sanitation costs due to improved water shed management. |
| **Cities** Increase vegetation and green spaces | Improved air quality reduced heat island impacts, lessened storm-water flooding, intercepted pollutants | Improved human resilience to extreme weather conditions; reduced levels of stress and mental health benefits; Increased outdoor physical and recreational activities and thus reduced obesity | Increased property value, reduced air conditioning costs. |
| **Energy** Clean energy supply and energy efficiency | Improved air quality | Reduced air pollution related diseases (e.g. respiratory ones) | Doubling of the share of renewable energy by 2030 would bring a global 1.1% GDP increase and 24 million jobs |
| **Sanitation** Provision of infrastructure | Improved water quality | Reduced morbidity and mortality from various diseases, in particular diarrhoeal diseases | US$ 1 invested in clean water and sanitation provides an economic return of between US$ 3 and US$ 34, depending on the region. |

*Figure 4.3 Co-benefits of mitigation[2].*



## 4.5 What are our existing challenges to adaptation and mitigation?

### 4.5.1 Policy on climate change ensures continuity of actions

Climate policy is central to guiding programmatic actions and ensuring consistency and continuity. Many international and regional policies are available to planners; however, a national policy is of paramount importance to ensure inclusion of the health component in climate change.

### 4.5.2 Existing policy framework on the African continent

Several organisations and institutions including the United Nations have developed policies, conventions and frameworks in Africa or applied them in Africa from elsewhere. The main UN-based policy emanates from the WHO, UNEP, UNFCCC, IPCC and World Meteorological Association. At the global level, the UNFCCC international treaty to address challenges of climate change was ratified by 192 countries, and the WHO supports health system strategies and actions on climate change and health. They are represented at the regional level in Africa. Their visions, and those of other agencies, are summarised in the Table 6.3 in Appendix 2.

### 4.5.3 Nationally Determined Contributions for reducing greenhouse gas emissions

Nationally Determined Contribution (NDCs) are climate action plans that a country submits to the UNFCCC in accordance with the Paris Agreement to reduce the global emission of GHGs (UNFCCC, 2015). The goal of NDCs is to monitor national progress. As shown in Figure 4.4, the process of formulating an NDC involves multiple steps. A country first undertakes a needs assessment in key sectors using the Situation Analysis and Needs Assessment (SANA) method, a risk assessment tool developed by the WHO (WHO, 2013). Next, a vulnerability assessment and adaptation exercise is undertaken to formulate NDCs containing climate-related policies, targets and measures governments

[2] UNEP green economy K1602727INF5Eng.pdf-2016 Healthy Environment Healthy People.

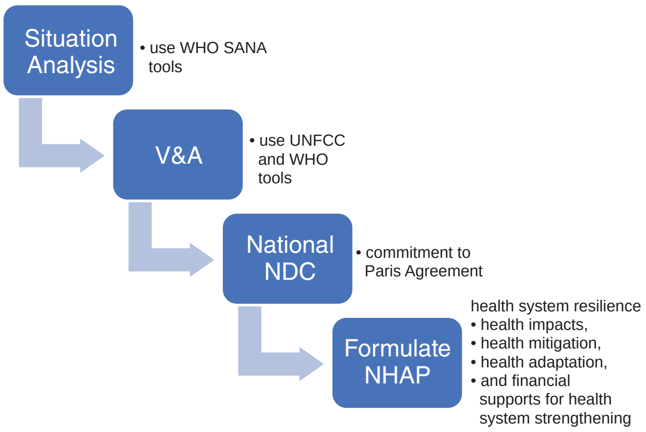



*Figure 4.4 The process of formulating a National Health Adaptation Plan (NHAP).*

aim to adapt and implement as a contribution to global climate action.

### 4.5.4 National Adaptation Plans for incorporating health in Nationally Determined Contributions

On the basis of the findings of the NDCs, countries then formulate a National Adaptation Plan (NAP). The goals of the NAP process are for countries to build resilience to the impacts of climate change through medium- to long-term planning, and to integrate adaptation into all relevant policies and strategies. While the adaptation components of NDCs are meant to internationally communicate a country's contribution on climate actions, the NAP processes are for domestic planning that allow a country to identify, address and review their evolving adaptation needs.

### 4.5.5 Intersectoral collaboration is critical for developing Nationally Determined Contributions and National Adaptation Plans

NDCs and NAPs are usually undertaken by a government's Ministry of environment or equivalent, and the health components are either missing or absent in most national plans. As elaborated in the preceding sections, climate change has a wide range of health effects that put an added burden on the health systems of countries in Africa. To cope with the accrued effects of climate change, the health system must be resilient: it must have the ability to protect health in normal and disaster situations, and to cope with the added demand for health care in disaster situations. However, in Africa, the Ebola epidemic and the COVID-19 pandemic have demonstrated that the health systems of several African countries are fragile and unable to respond to the needs in a timely and effective manner. The added health demands of climate change may put similar stress on the health system unless steps are taken to strengthen its resilience to climate change in Africa. Climate policies are essential for mitigating the health impacts of climate change and developing successful adaptation processes. Therefore the NAP must contain a health component, namely the National Health Adaptation Plan (NHAP), during formulation of the NAP. The NHAP incorporates health as four components, including impact assessment, mitigation, adaptation and financial support for health system strengthening (Figure 4.4). The NHAP is not a stand-alone document: it must be an integral part of a country's NDC.

The NHAP offers several competitive advantages in planning a sustainable health entity because it fulfils several objectives: (1) protecting population health is not missed as the health sector is not working in isolation, nor is it excluded in adaptation planning; (2) it maximises synergies and promotes health co-benefits across non-health sectors by collaborating and coordinating others such as energy, agriculture, housing and water, which may otherwise inadvertently formulate policies or implement programmes that cause or contribute to adverse health impacts; and (3) accessibility by the health sector to national adaptation funds such as the Least developed Countries Fund (LDCF), Adaptation Fund (AF), Green Climate Fund (GCF) and others is ensured by active participation of the health sector in financial discussions.

Public health adaptation to climate change in Africa is a joint commitment of the ministries of health and environment. NDC formulation in Africa is based on the Libreville Declaration between the WHO and UNEP

(WHO, 2015b). This Declaration calls upon UNEP and WHO to 'support, along with other partners and donors, including the African Development Bank (AfDB) and the African sub-regional economic communities to strengthen the strategic alliance between health and environment'. Therefore this process ensures synergies between health and other sectors and increases the co-benefits of adaptation and mitigation measures. Some model examples of national adaptation and mitigation plans have already been elaborated in section 4.4.2.

However, despite the above examples, surprisingly enough not all countries in Africa have formulated their NAP or HNAP in collaboration with their health sectors, despite the Libreville Declaration (WHO 2015b). A recent comprehensive global study, illustrated in Figure 4.5, shows that most countries in Africa mentioned health as part of their NAP (Dasandi *et al*., 2021).

However, mentioning health in the NAP without any concrete health actions does not ensure the validity of the HNAP, which that requires action in the four components mentioned above. The study of Dasandi *et al.* (2021) corroborates the findings of Nhamo and Muchuru (2019) who observed that most of the countries in Africa considered public health sector strengthening as part of their adaptation strategy; however, in most, it was not clear how the public health sector was going to be strengthened and how it would link to SDGs. Although the adaptation plans are in place, financial constraints are a problem for most countries, making implementation very slow. However, countries can access funding through the Least Developed Countries (LDC) work programme (Nhamo and Muchuru, 2019).To date, 31 countries have been financially supported by the Least Developed Countries Fund (LDCF) in preparing and submitting their National Adaptation Programme of Action (NAPA) to the UNFCCC. Limited access to this fund emphasises the fact that many countries do not have sufficient national capacity to undertake the formulation process for seeking funding, so local capacity building of intersectoral collaboration through the WHO HiAP must be promoted.

The challenge of integrating the health component into the NDC is a persisting one. Some potential explanations for this lack of support for health sector adaptation are (1) the health community being excluded or absent from the NAP process; (2) the health sector not submitting proposals to the NDC; (3) the proposals on health adaptation not meeting the minimum technical requirements; or (4) the process of arriving at an NHAP from



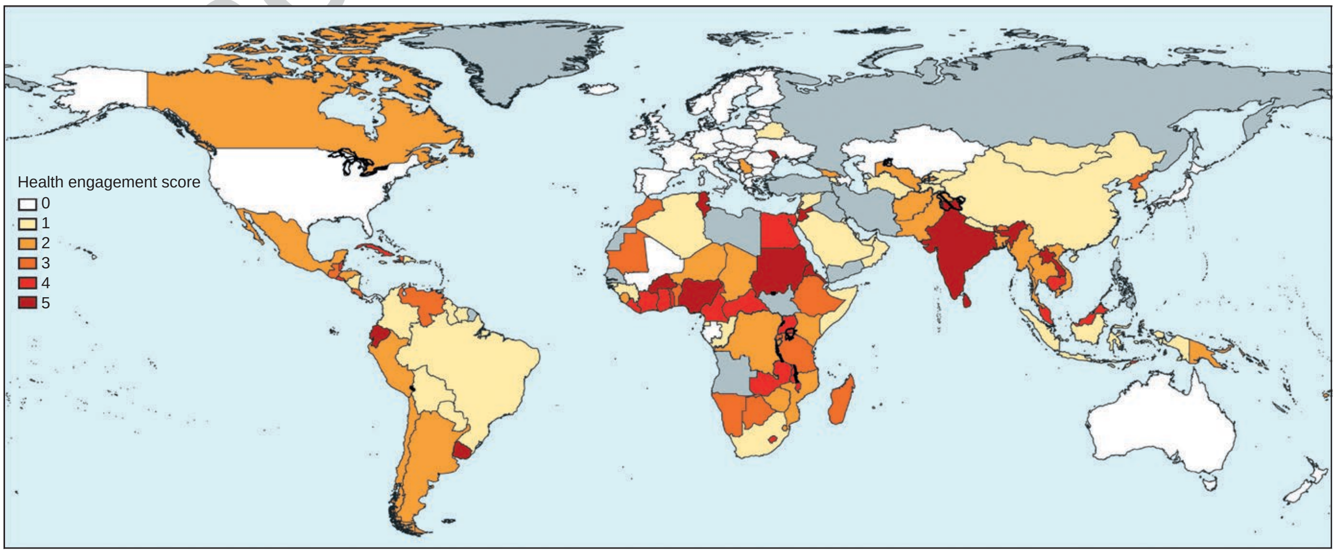



*Figure 4.5 The status of health in African NAPs.*

the NDC may be lengthy, cumbersome and outside the technical capacity of many African countries.

The NHAP should be considered as the health plan of the NDC and, as such, some of the challenges may be turned into opportunities for a set of actions to be implemented to protect vulnerable populations.

### 4.5.6 The double challenge of adaptation and mitigation in the face of the COVID-19 pandemic

The health and other consequences of climate change are insidious, but undeniably lead to measurable effects and calls for adaptation and mitigation strategies. The arrival of the COVID-19 epidemic compounded this goal. Two most pressing global health threats – the rapid emergence of the COVID-19 already claiming some quarter of a million lives and affecting millions in Africa, and the insidiously evolving climate crisis killing some 120,000 people for every 1 million exposed to climatic hazards in Africa annually – represent the convergence and interplay of two disasters that share common elements: for example, climate change affects cardiovascular and chronic pulmonary diseases, which are recognised risk factors for severe COVID-19. Furthermore, marginalised groups are at a higher risk than others for exposure to high levels of air pollution and associated chronic illnesses, as well as for COVID-19-related illness and deaths, thereby affecting equitable access to health services by overloading the health system and reducing access to health services (Sacks *et al.*, 2021). Hence both crises call for concerted preparedness and response. Hence, we must re-think our adaptation and mitigation strategies to protect our society, environment and health while not undermining the progress made on climate change so far.

The COVID-19 pandemic has so far resulted in a contraction of Africa's economy by some 2.6%, with a gross domestic product (GDP) loss of US$120 billion. Health care will require an additional US$100 billion in expenditure; 28.2 million to 49.2 million more Africans will fall back into extreme poverty; and more than 100 million people are at risk of hunger. An estimated 25 million to 30 million job losses are anticipated both in the formal and in the informal sectors. This comes on top of climate change-related projections that GDP in West and East Africa will contract by up to 15% by 2050, in North and Southern Africa by as much as 10% and in Central Africa by 5%. Crop yields could decrease by up to 15% while more frequent and more intense extreme weather events are predicted (African Union, 2020; Gondwe, 2020). Both COVID-19 and the climate crisis have exposed the fact that the poorest and most marginalised people in society, such as migrants and refugee populations, are always the most vulnerable to shocks and that the health systems in Africa are not sufficiently resilient to withstand the added pressure.

As Africa looks to recover from the economic devastation created by the COVID-19 pandemic, the time is right to set priorities for green transformations in the process. A price on carbon is essential for that growth not to lead to rapidly growing GHG emissions in the transport and energy sectors. A rapid global transition to clean energy sources is needed to end the stranglehold of fossil fuels. Curbing the drivers of climate change will help to suppress the emergence and re-emergence of zoonotic diseases that are made more likely by intensive farming and the international trade of exotic animals (Sack *et al.*, 2021).

The adaptive and mitigation strategies elaborated in the preceding section must be strengthened and all African governments should consider building a resilient health system to respond to the crisis of climate change, and present and future pandemics. In this tall undertaking, some guidance may be derived from the 'Green African Transformation (GREAT) Pathways – Building a partnership for Africa–European Union collaboration on low-carbon development' (INRA, 2021), provided these projects are evaluated by HiAP tools of a Health Impact

Assessment, the development pace of Africa is respected and that these projects can be supported from external sources.

## 4.6 System approach to developing coherent strategies: identifying synergies, disconnects and inadvertent consequences

Climate change interlinks us with natural elements we share, the air we breathe, the food we eat and the water we drink. It is clear from the evidence across different sectors addressed in chapter 3 that a coherent integrated strategy to climate change must be founded on the ecosystem approach encompassing the pillars of health, environment, economy and society. The negative effects of any one of the pillars will have spill-over effects on the remaining pillars. Conversely, the positive effect of one sector may have amplifying effects on the others. In such an interlinkage, there is interaction among decision-makers and implementors across different sectors. Obviously, human health is, in multiple connections, under the dependence of the climatic context. Any modification to the climate will have significant medical effects which could be mitigated according to the adaptive capacities of populations. But the adaptive capacity will depend on economic resilience, such as through a health insurance system. It is incumbent on policy-makers to balance the trade-offs in these pillars. For instance, unsustainable development, without due respect to society and health will widen the economic gaps and result in an unhealthy nation that will negatively affect the economy. African nations should encourage multidisciplinary research programmes on ecosystem dynamics in relation to pandemic outbursts.

Unintended negative health consequences can arise from many non-health sectors. To avoid duplication, redundancy and disconnect among all sectors, the WHO has proposed a Health in All Policy (HiAP) to encompass the root causes of ill-health. The fundamental causes of climate-related diseases are best mitigated at the root level; thus, the health component should be recognised and included during policy formulation and implementation in all sectors and during the planning and implementation of all development projects that affect climate and impact human health. The tool to achieve this is the Health Impact Assessment, which is covered under the HiAP to ensure that health is an integral part of all National Adaptation Plans. Public health issues should be central to environment dynamics, mainly to climate change challenges which could worsen climate-related effects, directly or indirectly, since public health is a key factor for development. African nations should devote more attention to the impacts of projects that negatively affect the development process.

### 4.6.1 Capitalising on synergies

Climate change is expected to have a variety of impacts in Africa, directly and indirectly, through social, economic and environmental dynamics, and across all sectors as seen from the evidence in chapter 3. Consequently, the journey to reaching national development goals can become more challenging, if the need for adaptation is not properly addressed. Conversely, if coherent action is taken to coordinate efforts across sectors, synergies can be found that will not only mitigate expected negative impacts but also turn them into new opportunities. The role of each stakeholder has to be clearly defined in a matrix system for the strategy to act in synergies, and to avoid duplication and redundancy so as to conserve limited resources. Cross-sectoral considerations must identify and highlight entry points for interventions that will lead to increased efficiency of budget allocation and policy implementation.

In the preceding section we have elaborated how intervention through mitigation and adaptation in one sector has multiplier effects and co-benefits in others. The strategies that more markedly contribute to the overall development of countries in Africa include capacity building and awareness raising, along with improved data collection and analysis.

**Table 4.1 Long-term impacts of climate change on Africa's GDPs**[3]

| Subregions | GDP (% Change/Year) | | | |
|---|---|---|---|---|
| | 1° C | 2° C | 3° C | 4° C |
| North (n = 7) | –0.76 ± 0.16 | –1.63 ± 0.36 | –2.72 ± 0.61 | –4.11 ± 0.97 |
| West (n = 15) | –4.46 ± 0.63 | –9.79 ± 1.35 | –15.62 ± 2.08 | –22.09 ± 2.78 |
| Central (n = 9) | –1.17 ± 0.45 | –2.82 ± 1.10 | –5.53 ± 1.56 | –9.13 ± 2.16 |
| East (n = 14) | –2.01 ± 0.20 | –4.51 ± 0.34 | –7.55 ± 0.63 | –11.16 ± 0.85 |
| Southern (n = 10) | –1.18 ± 0.64 | –2.68 ± 1.54 | –4.40 ± 2.56 | –6.49 ± 3.75 |
| Whole of Africa (n = 55) | –2.25 ± 1.52 | –5.01 ± 3.30 | –8.28 ± 5.12 | –12.12 ± 7.04 |

*Source:* Adapted from Economic growth, development and climate change in Africa, published by the African Climate Policy Centre (ACPC) of the United Nations Economic Commission for Africa (UNECA)



In addition, the implementation of HiAP was identified as an ideal intervention in many sectors including transportation, agriculture and the control of vector-borne diseases and zoonoses. The main expected benefits when considering cross-sectoral dynamics include a reduction in public spending along with an increase in public revenues through tax revenues and increased economic activity; employment creation across all sectors and interventions; improved well-being with better health and a reduction in injuries and diseases; and an amelioration of leisure opportunities for local populations and for tourism.

### 4.6.2 Avoiding disconnects as an unintended consequence

With the existence of a plethora of policy on climate change and health emanating from the AU, UNEP, UNFCCC and WHO, there is unavoidable redundancy leading to disconnect in the goals and strategies that must be avoided. One way to circumvent this challenge is to promote the HiAP approach. Some of the main potential unintended consequences of climate change initiatives identified in this report include the following:

- Achieving self-sufficiency in food security by planting maize, leading to an increased risk of cardiovascular diseases and diabetes.
- Promoting wood burning as a domestic fuel for cooking, causing the release of more particulate matter into the environment.
- Planting fire-resistant trees, leading to disruption of the ecosystem.

## 4.7 Wider economic and development consequences

Health is tied to the economic development pathway; a healthy nation is an economically productive one, and an economically productive nation is a healthy one. According to the International Monetary Fund, adverse consequences of climate change are concentrated in regions with relatively hot climates, where a disproportionately large number of low-income countries are located, as exemplified in Africa.

The African Climate Policy Centre projects that the GDP in the five African sub-regions will suffer significant decreases because of a global temperature increase. As elaborated in Table 4.1, different temperature rise scenarios will differently affect the GDP. For example, in scenarios ranging from a 1 °C to a 4 °C increase in global temperature relative to pre-industrial levels, the continent's overall GDP is expected to decrease by 2.25–12.12%. West, Central and East Africa exhibit higher adverse impacts than Southern and North Africa (ACPC, 2017). 3

GDP is affected by labour productivity. Another notable evaluation is by Kjellstrom

[3] Percentage change per year according to four global temperature increase scenarios for the five sub-regions and for the whole of Africa.

**Table 4.2 Economic impact of climate change**[4]

| | Total global net cost (% of total climate cost) | | Net cost in 2030 by specific country type | | |
|---|---|---|---|---|---|
| Impact component | 2010 | 2030 | Developing, low GHG emitters | Developing, high GHG emitters | Developed |
| Total climate change | 609 (100) | 4,345 (100) | 1,730 (100) | 2,292 (100) | 179 (100) |
| Labour productivity loss due to workplace heat | 311 (51) | 2,436 (56) | 1,035 (60) | 1,364 (60) | 48 (27) |
| Clinical health impacts | 23 (3.7) | 106 (2.4) | 84 (4.9) | 21 (0.9) | 0.002 (0.001) |

and McMichael (2013) which shows that heat affects labour productivity (Table 4.2). When the impacts are stratified, it is seen that labour productivity accounts for some 60% of the impacts. Since labour accounts for a significant proportion of the African economy, climate change will have far-reaching economic consequences.

The burden of disease and other health complications associated with climate change are heavy and put a significant strain on both public and private spending on the African continent. Case Study 8 from Benin illustrates how being out-of-pocket for health care is related to outbreaks of climate-sensitive diseases and drives affected communities to the verge of poverty.

The WHO's 'Atlas of African Region Health Statistics 2016' provides country-by-country figures (WHO, 2016a). The WHO data show that more than 50% of the health expenditure is borne by households, and the state contributes to less than 50% of health expenditure for an average household in West Africa, as in the African continent. According to the document, produced by the WHO's regional office for Africa, 'public spending on health' accounted for 49.5% of total health spending in Africa in 2013. For the 15 Economic Community of West African States (ECOWAS) countries, the average was 43.41% for the same year, according to a calculation by Africa Check. The highest percentages were recorded in Cape Verde (73.7%), Ghana (60.6%) and The Gambia (60.1%); the lowest in Sierra Leone (14.30%), Guinea-Bissau (20.30%) and Nigeria (23.90%).

As for 'private spending', in 2013 the average was 51% of the overall total for Africa and 56.46% for the 15 ECOWAS countries, with high percentages in Sierra Leone (86%), Guinea-Bissau (80%), Nigeria (76%) and the lowest in Cape Verde (26%). The share of households in these 'private expenditures' is not specified.

In addition to direct and indirect expenditures related to diseases caused by climatic or meteorological parameters (bioclimatology and biometeorology) or by the degradation of the quality of environmental factors (air, water and soil), there are other related factors of climate change, such as declining agricultural yields and land destruction by floods or by invasions of desert locusts; for instance, see Case Studies 3 and 5. The interrelationship of these elements must be considered in assessing the economic impacts of climate change from an ecosystem approach to the environment and economy of Africa, as illustrated in Figure 4.6.

For most African countries, agriculture accounts for an average of 22% of GDP, with extreme values ranging from 65% for Somalia to 2% for Libya. Livestock accounts for 50% of the rural economy, which employs more than 60% of the population. Any factor of climate change affecting plant and animal production imbalances the budget of African countries. This vulnerability jeopardises the



[4] Kjellstrom and McMichael (2013).

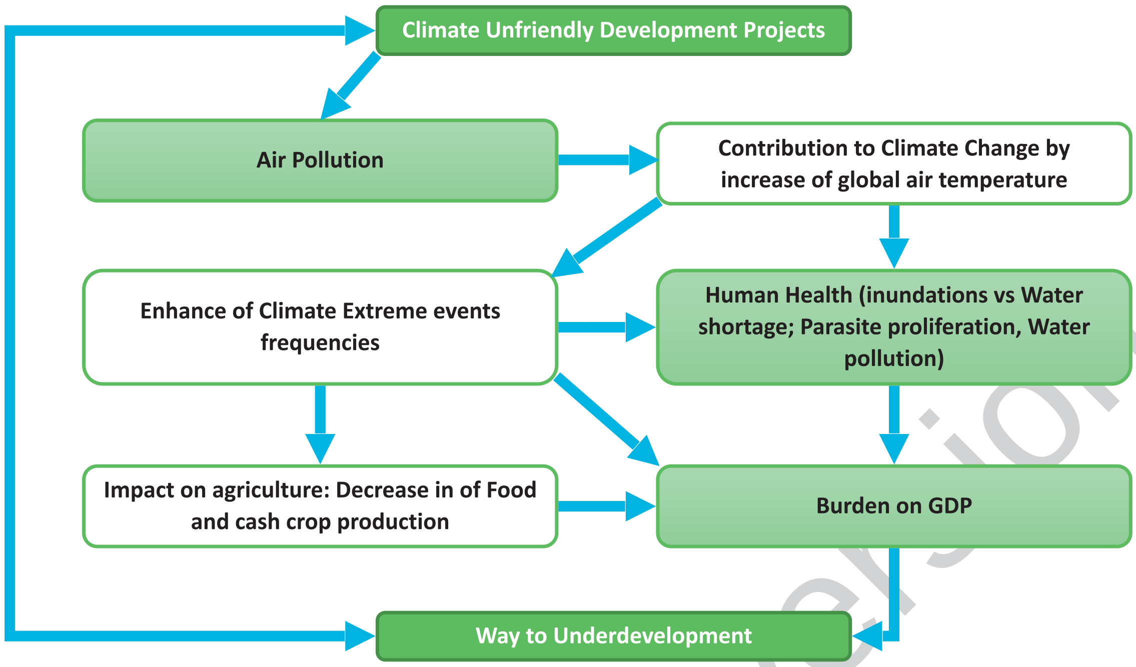



*Figure 4.6 Interrelationship of climate change and economic burden*[5].

continent's development and puts millions of Africans and their livelihoods at risk. According to current estimates, the negative effects of climate change are already reducing Africa's GDP by about 1.4%, and the costs of adapting to climate change are expected to reach 3% of GDP per year by 2030 (AfDB, 2019).

According to Sultan *et al.* (2014), it is projected that climate change will cause sorghum yield losses of about 12% in the mid-21st century across the Sahel, which is very consistent with the values found in the literature (Roudier *et al.*, 2011). However, this impact is very different between the western and central Sahel. Indeed, in the western Sahel, yield losses are particularly significant (around 19%) because of the combination of warming and declining precipitation at the beginning of the rainy season. In the central Sahel, temperature and precipitation are moving in the opposite direction: warming leads to yield losses, while the increase in rains at the end of the season is favourable for sorghum cultivation. Nevertheless, despite an increase in rainfall, it is the increase in temperatures that dominates the sign of the impacts of climate change in the central Sahel, with yield losses of around 7% in the middle of the 21st century. Comparison between the response of sorghum yield to climate change under the two fertilisation scenarios shows that an increase in inputs makes the crop more vulnerable to changes in temperature and precipitation, with greater yield losses when more inputs are added. This result is consistent with numerous studies that show that climate risk increases with intensification (Falconnier *et al.*, 2020). Similarly, scenarios for Tanzania, where agriculture accounts for about half of GDP and employs about 80% of the labour force, indicate that changes in climate could increase poverty and vulnerability. Scenarios for Namibia indicate that annual losses to the economy associated with the impacts of climate change on the country's natural resources could range between 1% and 4.8% of GDP. Ghana's economy and agricultural sector are particularly vulnerable because cocoa is the single most important export product and because it will be affected by changes in climate. Cocoa production is

[5] From Boko *et al.* (2007).

### Case Study 8 Economic impacts of climate change in Benin

*Background*. Climate changes amplify the burden of climate-sensitive diseases that must be managed to avert loss of lives and livelihoods. This study was chosen to illustrate the direct and indirect economic impacts of climate change on parents whose children were sicked in the Weme district of Benin using data on four common climate-sensitive childhood diseases: acute respiratory illness, malaria, diarrhoea and skin diseases, which are highly prevalent in Benin and show seasonal fluctuations. The choice of Benin was made because of the optimistic economic forecasts of Benin for the year 2025 to fit with the World Trade Organization projection of tourist entries. (Boko, 1988, 2014; Boko and Ogouwalé, 2007). The health impacts were evaluated by calculating the direct and indirect costs: direct costs consisted of the number of working days loss due to climate- and weather-induced diseases while indirect costs consisted of water quality degradation due to flooding, or
4 to water shortage, undernutrition, etc.(Makoutodé, 2015; Médéou, 2015).

*Main observations*. Impacts of the disease burden on the sick children result in 'time lost' by the parents. As shown in Figure 4.7, the duration of the 'time lost' by the parents varied from less than one week to more than one month. Thirty-five per cent of parents who lost between 2 and 3 weeks were generally in the category of single parents. By contrast only 10% of parents lost one month for treatment and for complete cure.

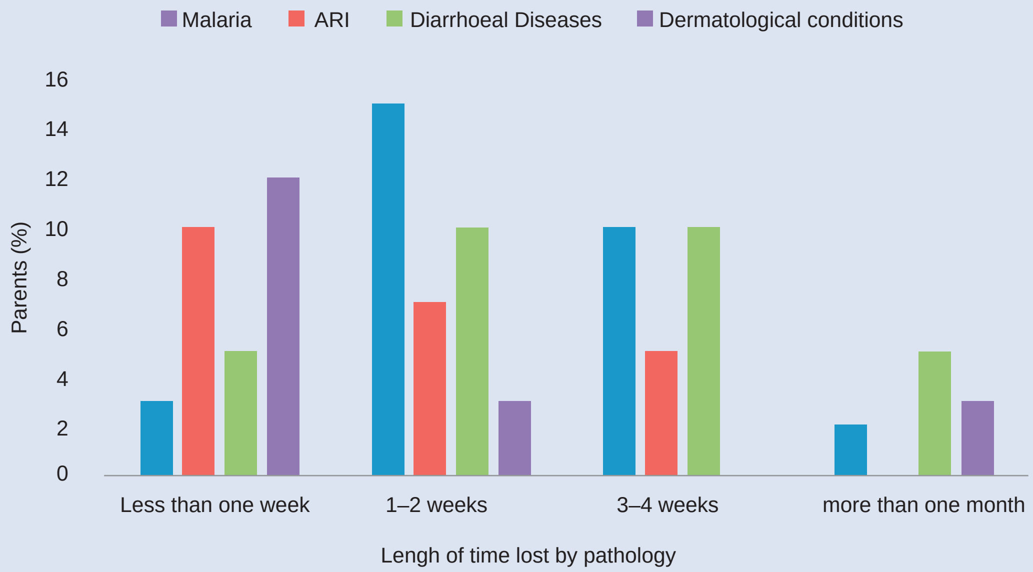



*Figure 4.7 Estimated duration of 'time lost' by parents of children affected by climate-sensitive diseases.*

As shown in Figure 4.8, 'time lost' by parents is attributed to absence from work (25%), fall in work performance (45%) and discontinuity of business (30%). These factors negatively affect the livelihood and economic gains of the parents whose children were affected by climate-sensitive diseases.

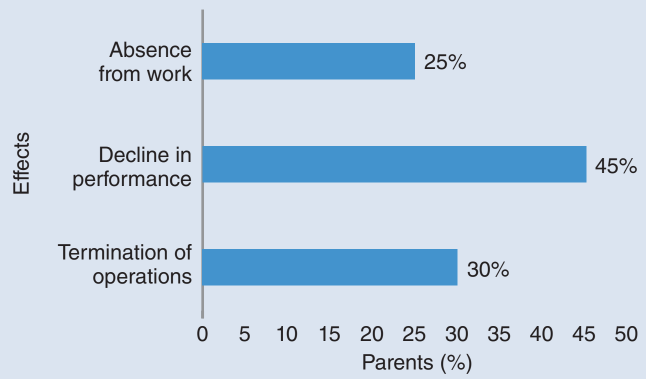



*Figure 4.8 Reasons for time lost by parents of sick children.*

The main observed outcome was 'time lost' by parents, which affected their work performance and consequently their ability to earn income. The 'lost time' by the parents depended on the types and severity of disease and the parents' socio-economic status: data collected during the study showed the amounts spent on medical treatment varied between 1,000 and 10,000 West African CFA francs each day. These costs increased by 30% on average for the adults, according to the nature and severity of the health impacts.

*Lessons learnt from this study*. Climate change is leading to a surge in climate-sensitive diseases, resulting in economic hardships for affected families and increasing poverty, which will undermine attaining the SDG of ending poverty. A holistic approach to adaptation must be practised to address the economic, social and environmental aspects of climate change.

thus central in debates on development and poverty alleviation (IPCC, 2014).

### 4.8 Conveying the urgency of the challenges: tackling barriers to implementation

Mitigation and adaptation for climate change and health effects face many barriers of misperception and misunderstanding. Mitigation and adaptation must be understood and addressed to enable progress in tackling the disaster associated with climate change. The UNFCCC's survey shows there is recognition of climate change such as increases in temperature and floods. However, since implementation of mitigation and adaptation measures has been limited, there are barriers at individual, government and private sector levels. Research is needed to elaborate individual and organisational motivations to convey the urgency of the challenges.

# 5 Conclusions and recommendations

## 5.1 What do we know and how do our recommendations address these concerns?

Climate change and health must be perceived in the context of sustainable development whereby we protect the well-being of the present population without endangering that of future generations. On the basis of the evidence reviewed in this report, including the evidence from the case studies, and considering previous work in this field, the working group formulated the following recommendations.

10. *Policy*. Climate policy is central to guiding programmatic actions and ensuring consistency and continuity. Although many international and regional policies are available to planners, to ensure inclusion of the health component in climate change, a national policy is of paramount importance.
    - Update policy to reflect emerging and current issues or expected pathways on national climate change and health.
    - Incorporate health in the Nationally Determined Contribution (NDC) during formulation of the national health adaptation plan as proposed by the Libreville Declaration. This will ensure inclusion of the health ministry in planning, monitoring and accessing available climate funds.
    - Conduct/complete the Situation Analysis and Needs Assessment (SANA) process to integrate health National Health Adaptation Plans (NHAPs) of all African countries, as recommended during the Paris Agreement.
11. *Intersectoral collaboration*. Since the NDC is usually undertaken by the Ministry of Environment, while the National Adaptation Plan (NAP) is usually undertaken by the Ministry of Health, the health component of climate change is either missing or incomplete.
    - Promote intersectoral collaboration across sectors at all stages from planning and implementation to monitoring and evaluation.
    - Mainstream the WHO Health in All Policies (HiAP) tool.
    - Promote a joint WHO–FAO, one-health approach to avert risk in agriculture and manage climate-sensitive zoonotic diseases.
12. *Data for policy and programmes*. Policy-makers, scientists and all relevant stakeholders need information for designing policy, implementing and monitoring programmes and setting priorities.
    - Roll out a robust database for collecting and analysing information on the prevalence of climatic hazards, their exposure pathways and related health conditions.
        - The climatic hazards of concerns for Africa include air and water quality, temperature and ocean rise, and extreme weather in the form of droughts, floods and storms.
        - Monitor ecological contamination of air and water media to detect toxic levels of air pollutants responsible for respiratory health conditions and water-borne diseases causing diarrhoea and infant mortality after flooding.
        - Institute the early-warning system of surveillance (EWARS) on vectors that may be amplified by climate change to avert outbreaks of climate-sensitive diseases such as malaria and other vector-borne and zoonotic diseases.
        - In countries where a systematic database cannot be implemented immediately, an early-warning system aiming at a climate-related event base surveillance system may be explored.
13. *Capacity building*. Africa needs a critical mass of climate scientists who are well versed in policy, programmes and research

and who can play important roles in the field and lead climate science in the region. To reach these goals, we make the following recommendations.

- Train policy-makers and government officials in the basics of climate change, policy-making, implementation, climate activity financing and emerging issues such as NetZero carbon policy to be able to negotiate at national, regional, and global levels and access various funding sources including the Green Climate funds and Africa–European Union collaboration.
- Produce graduate-level scientists qualified in climate change to manage the imminent crisis in Africa.
- Train climate scientists, health-care workers including practitioners to monitor epidemiological trends in climate-sensitive diseases, as well to detect, monitor and manage such diseases.

14. *Research*. Policy-makers need basic information generated within the African continent to make important decisions on choosing the best control strategies. Much international research on climate change in Africa is constrained by the lack of mutual agenda setting and benefits, and equality in decision-making between partners. This disequilibrium must shift to build research capacity.

- Foster formal arrangements with various partners such as the WHO Regional Office for Africa and the African Union. The Network of African Science Academies with its all its member academies should be supported to promote research.
- Research should, *inter alia*, be directed to fill the gaps in the dearth of information on the prevalence of climatic hazards in time and space; link disease mortality with exposure; elucidate the complex causal exposure pathways; and demonstrate the economic and health co-benefits of various adaptation and mitigation strategies.

15. *Health adaptation*. To avert and minimise the immediate adverse effects of climate change, protective actions must be implemented by communities, some of which are evident from the case studies in this report.

- Incorporate adaptative measures including EWARS in the national climate policy to detect warning signals due to climate change and adverse effects.
  - Develop EWARS for heat waves, hydrological disasters, vector controls and climate-sensitive diseases.
  - Develop strategies for coping with surges in adverse health impacts.
  - Anticipate and support vulnerable communities.
- Empower indigenous communities with the basic science of climate change to enable them to incorporate their knowledge into agricultural and cropping practices, including exploiting the planting of fire-resistant trees to limit forest fires, and drought- and pest-resistant crops to increase yields.
- Promote switching traditional cooking practices from biofuel to cooking stoves to reduce indoor air pollution.
- Encourage all communities to adapt their diets from high animal-based protein to plant- and insect-based protein.
- Adapt and mitigate to manage the inevitable adverse impacts of climate change in Africa.
- Integrate adaptation and mitigation strategies into short- and long-term development planning. Short-term measures include integrating climate adaptation and disaster risk reduction, while long-term mitigation measures require, governments, businesses and communities to prepare for climate impacts by reducing the carbon sink.

16. *Mitigation*. While adaptation measures provide immediate relief from the adverse effects of climate change, eventually these adverse effects overcome the adaptation measures and necessitate mitigation measures to reduce the carbon sink.

- Formulate and mitigate national mitigation strategies to reduce the carbon sink by incorporating it into NDCs.
- Reduce greenhouse gas (GHG) emissions across sectors that are big polluters, for example in urban transport, agriculture and forestry.
- Promote urban green spaces for planting trees to mitigate the effects of urban heat islands.
- Incorporate and sustain green technologies in post-COVID-19 recovery innovative technologies.
- Africa stands to benefit from integrated climate adaptation, mitigation and development approaches.
- In expanding economically and meeting their development needs, African countries have abundant opportunities to adopt clean, efficient low-carbon technologies and practices.
- Some low-carbon development options may be less costly in the long term and could offer new economic opportunities for Africa.
- Many of the measures to avoid GHG emissions provide generous gains in economic productivity, human development and quality of life. The adoption of a low-carbon pathway needs to fit into countries' specific national circumstances.

17. *Advocacy*. Awareness about climate change and health must be raised to set the public agenda and bring the issue to the attention of policy-makers and implementers.

- Simply climate change science including adaptation and mitigation measures to influence the social behaviour and practices of institutions and individuals.
  - Promote system dynamics and a participatory approach by engaging lay citizens, school children and youth to capture their innovative approach and guarantee the future of Africa.
- Target health risk communications to counter misinformation on climate change and health.
- Educate primary health care and community-level doctors in climate change, to make significant strides in advocating citizens to adopt lifestyle changes that limit carbon emissions and achieve better health.

18. *Partnership*. The agenda to avert the adverse health effects of climate change in Africa calls for substantial investment in knowledge, infrastructure, and human and financial resources. Climate change is a shared global problem that lies outside the political reach of any one nation state and requires a collective, global response. Therefore, international cooperation is vital to avert dangerous climate change.

- Forge multidisciplinary and transdisciplinary engagement at national, regional, and global levels.
- There is an urgent need to support Africa in dealing with its disproportionately high disease burden in relation to the low amount of GHGs. The European Union–Africa Green Climate cooperation is an exemplary initiative and may be replicated with developed countries, where most of the GHGs are produced.

Link climate action with specific provisions of SDGs, the New Urban Agenda, WHO Urban Health Research Agenda, AU Agenda 2063 and other regional networks such as the Southern African Development Community (SADC) and the African Continental Free Trade Area (AfCFTA).

## 5.2 How can we address the identified challenges?

The challenges of climate change threats are complex and require the contribution of experts across different disciplines and sectors. The overall messages of the working group on how to tackle the crisis of climate change and health have been presented in the preceding section. However, some messages deserve to be reiterated and as an overarching recommendation we reaffirm the top priority of stabilising climate and accelerating efforts to limit GHG emissions to achieve a zero-carbon economy before 2050.

## 5.3 Generating and using the evidence base

### 5.3.1 Filling knowledge gaps by research

- Policy-makers rely on valid information that is evidence based in nature, and evidence-based information is derived from fundamental research. However, research on climate change and health in Africa is constrained by the fact that there is a dearth of publications on climate change in Africa; most of the research is conceived outside Africa and published by non-Africans (Agyepong *et al*., 2017). Therefore, it is important to foster transdisciplinary and international collaborative research to generate evidence in the local context. The following are some of the research needs identified in this project.
- It will be important to invest more in climate change and health research in areas in Africa that are most affected by rising temperature, and by air-, water- and food-borne diseases that are more likely to be impacted by weather change. Actions for the control of infectious diseases and non-communicable diseases should consider adaptation needs to face climate change impacts in Africa. These studies should include, but not be limited to, conducting long-term observations of cohorts of persons to determine burdens of diseases associated with climate change. Another area is to include modelling studies to define current and future impacts.
- There is also an urgent need to find indigenous alternative African technologies for adaptation and mitigation such as planting fire-resistant trees and drought- and pest-resistant crops, and changing agricultural practices and dietary habits including the promotion of alternative protein sources such as insect-based proteins, etc.

### 5.3.2 Improving monitoring and integration of data sets

The quality of the data determines the extent to which they can be used in an evidence base. A set of data that is linked to the climate hazard exposure pathway with health linkage outcomes allows epidemiological analysis. But health is linked to economic development and social structure, so ideally such data should be collected to enable cross-linking of climate change and health to socio-economic determinants. In this respect, collaboration should be linked across different sectors such as meteorological, health and environmental data.



### 5.3.3 Galvanising international partnerships to meet the challenges of climate change

In relation to the amount of GHGs produced by Africa, the continent bears the highest global brunt from the disease burden attributed to climate change. The reasons for this uneven disease exposure have been summarised in this report. It is relevant to reiterate that the main blocks are financial, infrastructure and capacity. Climate change is a global issue that cannot be solved at national and regional levels. It is incumbent on the global community to support the laudable efforts of African governments in meeting the goals of climate change. In particular, enormous financial and technical support is needed to convert to green technology, and this is beyond the reach of most African countries, as elaborated in section 4.5.

### 5.3.4 Mainstream health in all policies

Recognising that negative health consequences arise from many non-health sectors, the WHO has proposed a Health in All Policy (HiAP) tool to encompass the root causes of ill-health. The fundamental causes of climate-related diseases are best mitigated at the root level; thus, health components should be recognised and included during policy formulation and implementation in all sectors and during the planning and implementation of all development projects impacting health. The main areas to be addressed are as follows:

- Ensuring that health is an integral part in all National Adaptation Plans.
- Consistently implementing WHO environmental health and climate change recommendations.
- Including HiAP to ensure intersectoral collaboration, especially for the control of vector-borne diseases, food security and agriculture, and air pollution in the transport sector.

### 5.3.5 Promote health risk communication

The time is now for effective health risk communication to raise awareness, set public agendas and sensitise stakeholders to counteract misinformation and enable everyone to contribute to adaptation and mitigation strategies. On the African continent, climate change and health are not widely available in formats that are understood and used by all citizens, policy-makers and governmental agencies; therefore there is an urgent need to raise awareness. Opportunities exist in the following domains:

- To counter misinformation and denial of scientific knowledge by vested groups to reduce polarisation in public and policy debates.
- To understand social behaviour by researching individual and institutional behaviour and to empower everyone to make informed decisions about climate change and health.
- To simplify adaptation and mitigation measures so that the attitudes and practices of citizens and governments can be changed to include the use of newer technologies for reduction of fire hazards, the over-dependence on animal proteins, etc.

### 5.3.6 What is the continuing role of academies?

The role of NASAC has remained 'to serve as an independent African forum that brings together academies of science in the continent to discuss science-related issues of common concern, to make joint statements on major issues relevant to Africa and to provide mutual support to member academies'. Governed by one framework, the NASAC Strategic Plan, science academies in Africa have also continued to pursue similar ambitions within their respective national settings (Figure 5.1).

The secretariat of NASAC in Nairobi, Kenya, has over the years provided a platform to coordinate interactions between national academies in Africa, and facilitate their meeting once a year at the Annual Meeting of African Science Academies (AMASA). AMASA has evolved to become an international forum for experts, policy- and decision-makers, as well as for relevant societal groupings and sectors to deliberate on various pertinent issues ranging from health, energy, manpower, agriculture and poverty alleviation, among others. Besides AMASA, NASAC has also successfully organised other major conferences and workshops across the continent, increased the capability of members' secretariats through training and capacity building support, and developed joint statements and policy-makers' booklets. In all the foregoing, science academies have remained the main interlocutors for making the voice of science heard in different spheres of development on the continent. In the same manner, and like other InterAcademy Partnership (IAP) initiatives, the member academies of NASAC have contributed to this African chapter of the global report on Climate Change and Health.

NASAC's networking capacity and engagement with numerous academies and organisations in and outside Africa has enabled it to continue to effectively disseminate information, centralise and coordinate efforts, and serve as the collective voice of the national science academies in Africa.

National academies of science, being merit-based institutions, must continue to recognise leading scientists (fellows, members, associates) in the fields of climate change

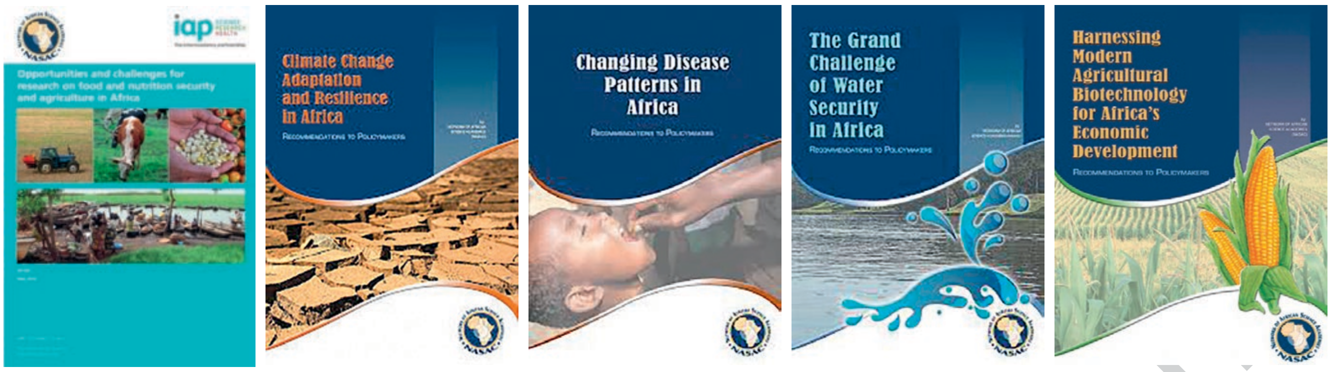



*Figure 5.1 NASAC's science policy reports.*

and health within and outside their respective countries. Academies must also utilise their membership for peer reviews of outputs on this topic to ascertain both merit and scientific excellence. In addition to their honorific role, national academies must continue to draw on the expert knowledge of their members to provide independent, high-quality advice to their governments and communities on the topic of climate change and health. The membership of NASAC has, unfortunately, experienced mixed levels of success in fulfilling this role. While some academies have excelled, it is evident that most academies experience inherent challenges of influencing policy. Academies continue to grapple with this challenge, which can almost always be attributable to the robustness of their infrastructure (leadership and/or secretariat), to their degree of influence beyond academia, the level and sustainability of their capital (financial and human) resources, and the degree to which their membership is engaged and committed to their cause. Be that as it may, academies must continue to provide credible science advice on pertinent topics such as climate change and health to guarantee science-informed policy-making. That is the only option to surmounting the challenges and building a track record of offering credible science advice to the most 'complex and wicked' developmental issues.

With the growing research output of African nations (SciDevNet, 2014), science academies have an increasingly important role to play in sourcing and utilising the best science to help meet shared challenges. Climate change and health is no exception. It is expected that this publication will provide global and regional science academies with the necessary impetus and recommendations that will inform deliberations on this topic across various sectors of society. The stakeholders within the academic, political and societal landscape must speak with one accord to champion sustainable development linked to climate change that is informed by science. That remains the paramount role that academies in Africa must continue to play and pursue.

# Appendix 1  Working group composition

| Name | Country | E-mail | Area of specialisation |
|---|---|---|---|
| Michel Boko | Benin | bokomichel@gmail.com | Environment and climate change |
| Issouf Traore | Burkina Faso | t_issouf2000@yahoo.fr | Tropical diseases, medical entomology, geography |
| Jean Marie Sabushimike | Burundi | sabujm2000@yahoo.fr | Climate change |
| Eugène Ndirahisha | Burundi | kabandaeugene@yahoo.fr | Health |
| Nde Peter Fon | Cameroon | ndepf@yahoo.com | Community health and health management |
| Armand Kablan | Côte d'Ivoire | kablan.malan@yahoo.fr; malan.kablan@univ-fhb.edu.ci | Hydrogeology and environmental engineering |
| Negussie Beyene | Ethiopia | negussie.beyene@gmail.com | Chemistry and public health (environment & health) |
| Belay Simane | Ethiopia | belay.simane@aau.edu.et | Environment and development studies |
| Samuel Sojinu | Nigeria | sojinuok2000@yahoo.com; sojinuos@funaab.edu.ng | Organic geochemistry |
| Ibrahim Sidi Zakari | Nigeria | sidizakariibrahim@gmail.com | Statistics |
| Anta Tal Dia | Senegal | adia@ised.sn; diagodia@gmail.com | Public health |
| Sokhna Thiam | Senegal | sokhna.thiam608@gmail.com | Epidemiology |
| Caradee Wright | South Africa | Caradee.Wright@mrc.ac.za | Public health, climate, and environmental health |
| Ama Essel | Ghana | amakwessel@yahoo.co.uk | Public health |
| Josephine Ngaira | Kenya | ngaira06@yahoo.co.uk | Geography |
| Babajide Alo | Nigeria | profjidealo@yahoo.com | Environmental chemistry, climate change and environmental management |
| Robin Fears | United Kingdom | robinfears@aol.com | Risk assessment |
| Deoraj Caussy | Mauritius | drdeorajcaussy@gmail.com | Epidemiology |
| Claudia Canales | Switzerland | canales.claudia@gmail.com | Plant genetics |

# Appendix 2 Supplementary Tables

## Summary of exposure pathways and health effects of air pollution

**Table 6.1 Summary of exposure pathways and health effects of major air pollutants**

| Pollutants | Exposure settings | Sources | Health effects |
|---|---|---|---|
| Carbon monoxide (CO) | Indoor and ambient environments | Outdoors: cars, trucks, other vehicles, or machinery burning fossil- or biomass fuels<br>Indoors: kerosene or gas heaters, leaking chimneys and furnaces, gas stoves, biomass stoves | Reduces the amount of oxygen transported in the bloodstream to critical organs such as the heart and brain.<br>At high levels, can cause dizziness, confusion, unconsciousness and death |
| Tropospheric ozone (ground-level ozone - $O_3$) | Ambient environment | Created by chemical reactions between oxides of nitrogen ($NO_x$) and volatile organic compounds (VOCs) in the presence of sunlight. Most likely to reach unhealthy levels on hot sunny days in urban environments | Even low levels can cause health effects. Can cause breathing difficulties, shortness of breath, pain while breathing, coughing and scratchy throat, as well as damaged airways. It can aggravate lung diseases (e.g. emphysema), increase frequency of asthma attacks and make lungs more susceptible to infection |
| Particulate matter (PM) | Indoor and ambient environments | Many particulates form as the result of complex reactions of chemicals, such as $SO_2$ and $NO_x$ stemming from industrial activities (e.g. power generation) and from vehicles. Particulate matter can be composed of acid, organic matter, metal and dust particles, for example<br>Outdoors: examples of anthropogenic sources:<br>• combustion processes<br>• mechanical, industrial or vehicular emissions<br>• cigarette smoke<br>• suspended pavement and road particles<br>• agriculture<br>Examples of natural sources:<br>• volcanoes<br>• forest/veld fires<br>• dust storms<br>• suspended sea salt<br>• pollen<br>• fungal aerosols<br>• resuspended sand<br>Indoors:<br>• the burning of non-electric fuels used for cooking and heating<br>• cleaning materials<br>• dust<br>• fungal aerosols<br>• incense<br>• cigarette smoke | The smaller the particle, the more harm can be done, as they can be inhaled ($PM_{10}$ can be inhaled deep into the lungs and $PM_{2.5}$ can get into the bloodstream) and cause serious health problems.<br>The health effects ultimately depend on the make-up of the particles (e.g. heavy metals will cause different health effects to pollen or dust).<br>Associations have been found between exposure to particulate matter and respiratory and cardiovascular ill-health-related morbidity and mortality, mental health effects, cancer, diabetes and more |

**Table 6.1 (*continued*)**

| Pollutants | Exposure settings | Sources | Health effects |
|---|---|---|---|
| Volatile organic compound (VOC), for example benzene, toluene, ethyl benzene, xylene | Indoor and ambient environments | Vehicles, industry (plasticisers, oils) solvents | Eye, nose and throat irritation, headaches, loss of coordination and nausea<br>Damage to liver, kidney and central nervous system<br>Some organics can cause cancer in animals, some are suspected or known to cause cancer in humans |
| Nitrogen dioxide ($NO_2$) | Ambient environment | Emissions from vehicles, power plants and off-road equipment that burns fuel | Irritated airways and aggravated respiratory diseases (particularly asthma) leading to respiratory symptoms such as coughing, wheezing and difficulties breathing |
| Sulphur dioxide ($SO_2$) | Ambient environment | Anthropogenic sources:<br>• power stations and industrial activities<br>• locomotives, ships, vehicles, and heavy equipment that burns fuel with high sulphur content<br>Natural sources: for example, volcanoes | Breathing difficulties (particularly for those who suffer from asthma), eye, ear, nose and throat irritations. Can exacerbate existing heart disease in sensitive groups |

## WHO vulnerability to climate change

**Table 6.2 Health impacts of climate change affecting vulnerable groups[1]**

| Drivers of vulnerability | Vulnerable population (may be applied as an indicator) | Drivers of vulnerability | Vulnerable population (may be applied as an indicator) |
|---|---|---|---|
| Vulnerability due to demographic factors | Proportion of children<br>Proportion of women<br>Proportion of elderly people<br>Population density | Vulnerability due to limited access to adequate resources | Unplanned urban housing / urban areas<br>Flood risk zones<br>Drought risk zones<br>Coastal storm and cyclone risk zones<br>Water-stressed zones<br>Food-insecure zones<br>Remote rural areas<br>Small islands |
| Vulnerability due to health status | Populations with HIV/AIDS<br>Populations with immunocompromised systems<br>Populations with tuberculosis<br>Malnourished and undernourished populations<br>Populations with infectious disease burden<br>Populations with chronic disease burden<br>Mentally or physically challenged people | Vulnerability due to limited access to adequate services | Health care<br>Potable water<br>Sanitation<br>Education<br>Shelter<br>Economic opportunities |
| Vulnerability due to culture or life condition | Impoverishment<br>Nomadic and semi-nomadic peoples<br>Subsistence farmers and fisherfolk<br>Ethnic minorities<br>Indentured labourers<br>Displaced populations<br>Refugees | Vulnerability due to geo-socio-political conditions | Conflict zones<br>Political stability<br>Existence of complex emergencies or conflict<br>Freedom of speech and information<br>Types of civil rights and civil society |

[1] Adapted from ClimDev-Africa (2013) and WHO (2013).

## Supplementary table on existing climate policy in the African region

**Table 6.3 Summary of main policy on climate action in Africa**

| Organisation | Main thrust of policy/strategy or vision |
| --- | --- |
| WHO-Geneva | Supports health systems in all countries, identifies strategies and actions, shares knowledge and good practices, and works in partnership with other agencies on climate change and health |
| WHO-AFRO | Same functions as WHO-Geneva but focuses on African priorities, most of its programmes on climate change and health are carried under the Protection of Health and Environment |
| WHO-developed SANA tool | The national plans of action on climate change and health are based on evidence from a Situation Analysis and Needs Assessment (SANA) that establishes baseline information on where a country stands in relation to eleven action points within the Libreville Declaration; its aim is to help national authorities establish milestones on health and environment, particularly to achieve the Millennium Development Goals |
| WHO-UNEP Libreville Declaration | Calls upon the United Nations Environment Programme (UNEP) and the World Health Organization (WHO) to 'support, along with other partners and donors, including the African Development Bank (AfDB) and the African sub-regional economic communities, the implementation of this Declaration' |
| African Union | African Union Agenda 2063: builds on, and seeks to accelerate, the implementation of past and existing continental initiatives for growth and sustainable development at the regional level |
| African Climate Policy Centre (ACPC) | Focuses on poverty reduction through mitigation and adaptation to climate change in Africa and to improve the capacity of African countries to participate effectively in multilateral climate negotiations |
| United Nations Framework Convention on Climate Change (UNFCCC) | International treaty to address challenges of climate change, ratified by 192 countries<br>Entered force on 21 March 1994 by the Kyoto Protocol |
| UNFCCC planning tool National Adaptation Programmes of Action (NAPAs) | In support of implementation of article 4.6 of the COP convention, the UNFCCC developed the programme of work for adaptation for LDCs. NAPAs provide important ways of prioritising urgent adaptation needs for least developed countries |
| Nairobi Work Programme, UNFCCC | assist all Parties, including the least developed countries and small island developing states, to improve their understanding and assessment of impacts, vulnerability, and adaptation, and to make informed decisions on practical adaptation on impacts |
| Durban Declaration, UNFCCC | advocated health benefits of climate change mitigation to protect public health |
| Intergovernmental Panel on Climate Change (IPCC), a joint UNEP–WMO programme | Provides policy-makers with regular scientific assessments on climate change, |

# List of tables


| | | |
|---|---|---|
| Table 3.1 | Projected annual mortality ranges due to cyclones and coastal floods | 25 |
| Table 3.2 | Global and African deaths due to air pollution | 42 |
| Table 3.3 | Crime records in flood-affected areas for 2011, 2012 and 2013 | 50 |
| Table 4.1 | Long-term impacts of climate change on Africa's GDPs | 66 |
| Table 4.2 | Economic impact of climate change | 67 |
| Table 6.1 | Summary of exposure pathways and health effects of major air pollutants | 78–79 |
| Table 6.2 | Health impacts of climate change affect vulnerable groups | 79 |
| Table 6.3 | Summary of main policy on climate action in Africa | 80 |

## List of figures


| | | |
|---|---|---|
| Figure 3.1 | Highest disease burden due to climate change in Africa | 18 |
| Figure 3.2 | Exposure pathways and health effects of climate change | 19 |
| Figure 3.3 | Projected model for heat rise in Africa | 20 |
| Figure 3.4 | Mount Kilimanjaro, showing the receded ice cap on Kibo peak at 5685 metres | 21 |
| Figure 3.5 | Study area in Cocody | 23 |
| Figure 3.6 | Vulnerability to (a) flood and (b) heat in Cocody | 24 |
| Figure 3.7 | Spread of locust swarms in 15 semi-arid counties of Kenya | 29 |
| Figure 3.8 | Locust outbreak threatens food security in semi-arid Kenya. | 30 |
| Figure 3.9 | Historical seasonal (March–May) rainfall totals in Kisumu, Kenya | 32 |
| Figure 3.10 | Interrelationships of infectious diseases and exposure pathways | 34 |
| Figure 3.11 | Exposure of children to dirty fuels of coal-burning stoves and a clean LPG stove | 43 |
| Figure 3.12 | Screen shots of the Arlit mobile application on air pollutants and health | 45 |
| Figure 3.13 | Disaster displacement in sub-Saharan Africa | 49 |
| Figure 4.1 | The main vulnerable regions of Africa | 55 |
| Figure 4.2 | The linkage between vulnerability and adaptation and mitigation | 58 |
| Figure 4.3 | Co-benefits of mitigation | 61 |
| Figure 4.4 | The process of formulating a National Health Adaptation Plan (NHAP) | 62 |
| Figure 4.5 | The status of health in African NAPs | 63 |
| Figure 4.6 | Interrelationship of climate change and economic burden | 68 |
| Figure 4.7 | Estimated duration of 'time lost' by parents of children affected by climate-sensitive diseases. | 69 |
| Figure 4.8 | Reasons for time lost by parents of sick children | 69 |
| Figure 5.1 | NASAC's science policy reports | 76 |

# Abbreviations

| | |
|---|---|
| AU | African Union |
| COP | Conference of the Parties |
| COVID-19 | Coronavirus disease 2019 |
| CRED | Climate and Regional Economics of Development<br>Centre for Research on the Epidemiology of Disasters |
| EASAC | European Academies' Science Advisory Council |
| EM-DAT | A global database on natural and technological disasters |
| EWARS | Early-warning system |
| FAO | Food and Agriculture Organization of the United Nations |
| GBD | Global Burden of Disease |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| HiAP | Health in All Policy |
| HIV/AIDS | Human immunodeficiency virus/acquired immunodeficiency syndrome |
| IAP | InterAcademy Partnership |
| IPCC | Intergovernmental Panel on Climate Change |
| LPG | Liquefied petroleum gas |
| NAP | National Adaptation Plan |
| NAPA | National Adaptation Programme of Action |
| NASAC | Network of African Science Academies |
| NCD | Non-Communicable Disease |
| NDC | Nationally Determined Contribution |
| OCHA | United Nations Office for the Coordination of Humanitarian Affairs |
| PM | Particulate matter |
| SDG | Sustainable Development Goal |
| SIDS | Small Island Developing States |
| UN | United Nations |
| UNECA | United Nations Economic Commission for Africa |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VOC | Volatile organic compound |
| WBD | Water-borne disease |
| WHO | World Health Organization |
| WHO-AFRO | World Health Organization for Africa |
| WMO | World Meteorological Organization |

# AUTHOR QUERY FORM

Dear Author,

During the preparation of your manuscript for publication, the questions listed below have arisen. Please attend to these matters and return this form with your proof.

Many thanks for your assistance.

| Query | References Query | Remarks |
|---|---|---|
| 1 | AUTHOR: "Begin, A. (2004)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 2 | AUTHOR: "Boko N. P. M., Médéou K. F., Vissin E. W., Blazejczyk K., et al. (2014a)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 3 | AUTHOR: "Brown, O. (2008)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 4 | AUTHOR: "Goergen, G., Kumar, P. L., Sankung, S. B., Togola, A. and Tamò, M. (2016)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 5 | AUTHOR: "Hess, C. and Macgregor, J. (2009)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 6 | AUTHOR: "IUCN" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 7 | AUTHOR: "Mudie, K., Jin, M. M., Tan, L. K., Addo, J., et al. (2018)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 8 | AUTHOR: "NASAC (2018a)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 9 | AUTHOR: "Ogouwalé E. (2006)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 10 | AUTHOR: "Thiam, S., Diène, A.N., Sy, I., Winkler, M.S., et al. (2017)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 11 | AUTHOR: "Wanjiru, H. (2018)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |
| 12 | AUTHOR: "Wright, C. Y., Garland, R. M., Norval, M. and Vogel, C. (2014)" has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List. | |

# REFERENCES


Abeli, T., Jäkäläniemi, A. and Gentili, R. (2014). Living with extremes: the dark side of global climate change. *Plant Ecology* **215**: 673–675.

Acheson, D. W. K. (2009). Food and waterborne illnesses. In: *Encyclopedia of Microbiology* (3rd edn) (ed. Schaechter, M.), pp. 365–381. Oxford, UK: Academic Press. https://doi.org/10.1016/B978-012373944-5.00183-8.

Adefeso, I. B., Sonibare, J. A. and Isa, Y. M. (2020). Further evidence on environmental impacts of carbon monoxide from portable power generator on indoor air quality. *Cogent Engineering* **7**: 1809771.

Adesinaa, J. A., Piketha, S. J., Qhekwanaa, M., Burgera, R., *et al.* (2020). Contrasting indoor and ambient particulate matter concentrations and thermal comfort in coal and non-coal burning households at South Africa highveld. *Science of the total environment* **699**: 134403.

Adeloye, D., Sowunmi, O. Y. and Chan, K. Y. (2018). Estimating the incidence of breast cancer in Africa: a systematic review and meta analysis. www.ncbi.nim.nih.gov.

AfDB (2011). Advisory: African Private Investment Guidance. Oil and Gas Strategy. Tunis.

AfDB (2019). Africa Climate Change Fund https://www.afdb.org/en/documents/africa-climate-change-fund-annual-report-2019.

African Union (2020). Impact of the Coronavirus COVID-19–19 on the African Economy. https://au.int/sites/default/files/documents/38326-doc-COVID-19-19_impact_on_african_economy.pdf.

Agyepong, I. A., Sewankambo, N. and Binagwaho, A. (2017). The path to longer and healthier lives for all Africans by 2030: the Lancet Commission on the future of health in sub-Saharan Africa. *The Lancet Commissions* **390** (10114): 2803–2859.

Aguilar, E. (2009). Changes in temperature and precipitation extremes in Western Africa, Guinea Conakry, and Zimbabwe. *Journal of Geophysical Research* **114** (D2): 2156–2202.

Ahmed, R, Ryan, R and Kevin, M. (2017). The epidemiology of non-communicable respiratory disease in sub-Saharan Africa, the Middle East, and North Africa. *Malawi Medical Journal* **29** (2): 203–211.

Akinsanola, A. A., Zhou W., Zhou T. and Keenleyside, N. (2020). Amplification of synoptic to annual variability of West African summer monsoon rainfall under global warming. *Climate and Atmospheric Science* **3** (1): 1–10.

Andreae, M. and Merlet, P. (2001). Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles* **15**: 955–966.

Asefi-Najafabady, S., Vandecar, K. L., Seimon, A., Lawrence, P. and Lawrence, D. (2018). Climate change, population, and poverty: vulnerability and exposure to heat stress in countries bordering the Great Lakes of Africa. *Climatic Change* **148**: 561–573.

Ashmore, M. R. and Dimitroulopoulou C. (2009). Personal exposure of children to air pollution. *Atmospheric Environment* **43**: 128–141.

Åström, C. (2014). Dengue, in World Health Organization's "Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s". Geneva.

Auld, H., Maciver, D. and Klaassen, J. (2004). Heavy rainfall and waterborne disease outbreaks: the Walkerton example. *Journal of Toxicology and Environmental Health A* **67**: 1879–1887.

Begin, A. (2004). Malaria, in world Health Organization's Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva.

Benue State Police Command (2016). Crime statistics 2012 to 2013.

Bidassey-Manilal, S., Caradee, W. Y. Engelbrecht, J. C., *et al.* (2016). Students' perceived heat-health symptoms increased with warmer classroom temperatures. *International Journal of Environmental Research and Public Health* **13** (6): 566.

Bifulco, M. and R. Ranieri (2017). Impact of drought on human health. *European Journal of Internal Medicine* **46**, e9–e10.

Birkmann, J., Cardona, O. D., Carreño Tibaduiza, M. L. and Barbat, A. H. (2013). Framing vulnerability, risk and societal responses: The MOVE framework. *Natural Hazards* **67** (2): 193–211.

Bless, P. J., Muela Ribera, J., Schmutz, C., Zeller, A. and Mausezahl, D. (2016). Acute gastroenteritis and campylobacteriosis in Swiss primary care: the viewpoint of general practitioners. *PLoS ONE* **11** (9): e0161650.

Blauw, L. L., Ahmad Aziz, N., Tannemaat, M. R., *et al.* (2017). Diabetes incidence and glucose intolerance prevalence increase with higher outdoor temperature. *BMJ Open Diabetes Research and Care* **5** (1), e000317.

Boko, M. (1988). Climats et communautés rurales du Bénin : rythmes climatiques et rythmes de développement. Thèse de Doctorat d'Etat ès Lettres, Université de Bourgogne, Vols I and II, Dijon, UA 909, CNRS, 607.

Boko, M., Niang, I., Nyong, A., Vogel, C., *et al.* (2007). Africa: Climate Change 2007 Impacts, Adaptation and Vulnerabilities. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press: 433–467.

Boko N. P. M., Médéou K. F., Vissin E. W.,
2 Blazejczyk K., *et al.* (2014a). Caractérisation des ambiances bioclimatiques dans les villes littorales du Bénin (Afrique de l'Ouest). In XXVIIe Colloque de l'Association Internationale de Climatologie, 2–5 juillet 2014, Dijon, France, pp. 605–611.

Boughédaoui, M., Chikhi, S., Driassa, N., *et al.* (2009). Caractérisation du parc de véhicule algérien et son usage. Environment and Transport in different contexts / Environnement et Transports dans des contextes différents. ENP Alger, COSGhardaïa, T., Algérie, Univ. Blida, INRETS. 201–208.

Brasseur, G. P. (2009). Implications of climate change for air quality. *WMO Bulletin* **58** (1): 10–15.

British Petroleum (BP) (2012). "Statistical Review of World Energy".

Brown, L. S. and Lankford W. F. (2015). Sustainability: clean cooking empowers women. *Nature* **521** (7552): 284–285.

3 Brown, O. (2008). Migration and climate change. IOM Migration Research Series No. 31. Geneva: International Organization for Migration.

Brown, S., Kebede, A. S. and Nicholls, R. J. (2011). Sea-level rise and impacts in Africa, 2000 to 2100. School of Civil Engineering and the Environment University of Southampton, UK.

Brown, S., Kebede, A. S. and Nicholls, J. (2011). Sea-level rise and impacts in Africa, 2000–2100. Online at: http://www.unep.org/climatechange/adaptation/Portals/133/documents/AdaptCost/9%20Sea%20Level%20Rise%20Report%20Jan%202010.pdf.

Burke, M., Gong, E. and Jones, K. (2015). Income shocks and HIV in Africa. *The Economic Journal* **125** (585): 1157–1189.

Butler, C. (2016). "Climate change and global health", CABI.and Recommendations for Africa. Available at https://www.uneca.org/sites/default/files/PublicationFiles/policy_brief_2_vulnerability_to_climate_change_in_africa_challenges_and_recommendations_for_africa.pdf. [Accessed 27 July 2020]. (2013).

Caminade, C., McIntyre, M. K. and Jones, A. E. (2016). Climate change and vector-borne diseases: where are we next heading? *Journal of Infectious Diseases* **214**: 1300–1301.

Caradee, W. Y., Street, R. A., Cele, N., Kunene, Z., *et al.* (2017). Indoor temperatures in patient waiting rooms in eight rural primary health care centers in northern South Africa and the related potential risks to human health and wellbeing. *International Journal of Environmental Research and Public Health* **14** (1): 43.

CDC (2018). Center for Disease Control and Prevention. https://www.cdc.gov/nceh/drought/implications.htm.

Checkley, W., *et al.* (2000). Effects of El Niño and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. *The Lancet* **355** (9202): 442–450.

Chersich, M. F., Swift, C. P., Edelstein, I., Breetzke, G., *et al.* (2019). Violence in hot weather: will climate change exacerbate rates of violence in South Africa? *South African Medical Journal* **109** (7): 447–449.

Chersich, M. F., Wright, C.-Y., Venter, F., *et al.* (2018). Impacts of climate change on health and wellbeing in South Africa. *International Journal of Environmental Research and Public Health* **15** (9): 1884.

Cheung, M. (2010). Large scale redistribution of maximum fisheries catch potential under climate change in the Northeast Atlantic. *ICES Journal of Marine Science* **68** (6): 1008–1018.

Chillrud, S. N., Ae-Ngibise, K. A., Gould, C. F., *et al.* (2021). The effect of clean cooking interventions on mother and child personal exposure to air pollution: results from the Ghana Randomized Air Pollution and Health Study (GRAPHS). *Journal of Exposure Science & Environmental Epidemiology* **31**: 683–698 (2021).

Cianconi, P., Betrò S. and Janiri, L. (2020). The impact of climate change on mental health: a systematic descriptive review. *Frontiers in Psychiatry* **11**: 74.

Cissé, G. (2019). Food-borne and water-borne diseases under climate change in low- and middle-income countries: Further efforts needed for reducing environmental health exposure risks. *Acta Tropica* **194**: 181–188. https://doi.org/10.1016/j.actatropica.2019.03.012.

Clarkson, G., Dorward, P., Osbahr, H., Torgbor, F. *et al.* (2019). An investigation of the effects of PICSA on smallholder farmers' decision-making and livelihoods when implemented at large scale–the case of Northern Ghana. *Climate Services* **14**: 1–14.

ClimDev-Africa (2013): African Climate Policy Centre (ACPC). Policy Brief, Climate Change and Health in Africa: Issues and Options.

ClimDev-Africa (2013a). Vulnerability to climate change in Africa: Challenges and recommendations for Africa. 2013 (Retrieved 27 July 2020), from www.Uneca.Org/sites/default/files/publicationfiles/policy_brief_2_vulnerability_to_climate_change_in_africa_challenges_and_recommendations_for_africa.Pdf.

Cochrane, M. A. and Laurance, W. F. (2002). Fire as a large-scale edge effect in Amazonian forests. *Journal of Tropical Ecology* **18**: 311–325.

Conway, D., Nicholls, R. J., Brown, S., Tebboth, M. G., *et al.* (2019). The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions. *Nature Climate Change* **9** (7): 503–511.

Cooper, P. J. M., Dimes, J., Rao, K. P. C., Shapiro, B., *et al.* (2008). Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems & Environment* **126** (1–2): 24–35.

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S. and Bellamy, R. (2009): Managing the health effects of climate change. Lancet and University College London Institute for Global Health Commission. *The Lancet* **373**: 1693–1733.

CRED Crunch (2019). Disasters in Africa: 20 Year Review (2000–2019*), ISSUE NO. 56.

Daron, J. D. (2014). Regional Climate Messages: East Africa Scientic Report from the CARIAA-Adaptation at scale in semi-arid regions (ASSAR) Project.

Dasandi, N., Graham, H., Lampard, P. and Mikhaylov, S. J. (2021). Engagement with health in national climate change commitments under the Paris Agreement: a global mixed-methods analysis of the nationally determined contributions. *The Lancet Planetary Health* **5** (2): e93–e101.

David, J. M., Ravel, A., Nesbitt, A., Pintar, K. *et al.* (2014). Assessing multiple foodborne, waterborne, and environmental exposures of healthy people to potential enteric pathogen sources: effect of age, gender, season, and recall period. *Epidemiology & Infection* **142** (1): 28–39.

Depietri, Y., Welle, T. and Renaud, F. G. (2013). Social vulnerability assessment of the Cologne urban area (Germany) to heat waves: Links to ecosystem services. *International Journal of Disaster Risk Reduction* 6: 98–117.

Dongo, K., Kablan, A. K. M. and Kouamé, F. K. (2018). Mapping urban residents' vulnerability to heat in Abidjan, Côte d'Ivoire. *Climate and Development* **10** (7): 600–613.

Dorner, S. M., Anderson, W. B., Slawson, R. M., Kouwen, N. and Huck, P. M. (2006). Hydrologic modeling of pathogen fate and transport. *Environmental Science & Technology* **40**: 4746–4753.

Dorward, P., Clarkson, G. and Stern, R. (2015). Participatory integrated climate services for agriculture (PICSA): Field manual.

Dosio, A., Jones, R. G., Jack, C., Lennard, C., Nikulin, G., *et al.* (2019). What can we know about future precipitation in Africa? Robustness, significance and added value of projections from a large ensemble of regional climate models. *Climate Dynamics* **53** (9–10): 5833–5858.

Ebi, K. L., Ndebele-Murisa, M., Neasham, A. J. and Schleyer, M. (2014). IPCC WGII AR5 Chapter 22. Africa.

Ebi, K., Berry, P., Campbell-Lendrum, D., Corvalan, C., *et al.* (2002). Protecting Health from Climate Change. Vulnerability and Adaptation Assessment. World Health Organization.

El-Fadel, M., Ghanimeh, S., Maroun, R. and Alameddine, I. (2012). Climate change and temperature rise: implications on food- and water-borne diseases. *Science of the Total Environment* **437**: 15–21.

EM-DAT, the International Disaster Database. CRED/UCLouvain (2020). https://www.emdat.be/database accessed on 20 June 2020.

Engelbrecht, F., Adegoke, J., Bopape, M., *et al.* (2015). Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environmental Research Letters* **10**: 085004.

Essoh, N. P. S. (2013). Shipping and Invasion of second-hand vehicles in west African ports: analyzing the factors and market effects at the port of Abidjan. *American Journal of Industrial and Business Management* **3**: 209–221.

European Respiratory Society (2017). Forum of International Respiratory Societies.

Falconnier, G. N., Corbeels, M., Boote, K., *et al.* (2020). Modelling climate change impacts on maize yields under low nitrogen input conditions in sub-Saharan Africa. *Global Change Biology* **26** (10): 5942–5964.

FAO (2005). 31st Session of the Committee on World Food Security. Special Event on Impact of Climate Change, Pests and Diseases on Food Security and Poverty Reduction. Background Document.

FAO (2012). State of the world forests. Rome, Italy: FAO. (Retrieved 30 June 2020), from http://www.fao.org/docrep/016/i3010e/i3010e00.htm.

FAO- IFAD, UNICEF, WFP and WHO (2019). The state of food security and nutrition in the world 2019: safeguarding against economic slowdowns and downturns, Rome, Italy.

FAO (2020). The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. FAO. Rome.

FAO (2020a) *Emergencies, and the Desert Locust Crisis in the Horn of Africa:* www.fao.org/emergencies/crisis/desertlocust/intro/en/. Accessed 3 April 2020.

Ferguson, C., Husman, A. M. D. R., Altavilla, N., Deere, D. and Ashbolt, N. (2003). Fate and transport of surface water pathogens in watersheds. *Critical Reviews in Environmental Science and Techology* **33** (3): 299–361.

Fisher, S., Bellinger, D. C., Cropper, M. L., Kumar, P. *et al.* (2021). Air pollution and development in Africa: impacts on health, the economy, and human capital. *Lancet Planet Health* **5**: e681–88.

Fischler, F., Wilkinson, D., Benton, T., Daniel, H., *et al.* (2015). The role of research in global food and nutrition security-Discussion paper.

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., *et al.* (2011). A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management* **8**: 1.

Fong, T. T., Mansfield, L. S., Wilson, D. L., Schwab, D. J., Molloy, S. L. and Rose, J. B. (2007). Massive microbiological groundwater contamination associated with a waterborne outbreak in Lake Erie, South Bass Island, Ohio. *Environmental Health Perspectives* **115**: 856–864.

Fouque, F. and Reeder, J. C. (2019). Impact of past and on-going changes on climate and weather on vector-borne diseases transmission. a look at the evidence. *Infectious Diseases of Poverty* **8**: 51.

Freeman, J. T., Anderson, D. J. and Sexton, D. J. (2009). Seasonal peaks in *Escherichia coli* infections: possible explanations and implications. *Clinical Microbiology and Infection* **15**: 951–953.

Friel, S. K., Bowen, I. D., Campbell-Lendrum, H., Frumkin, A. J., *et al.* (2010). Climate change, non-communicable diseases, and development: the relationships and common policy opportunities. *Annual Review of Public Health* **32**: 133–147.

Funk, C., Husak, G., Michaelsen, J., Shukla, S., *et al.* (2013). Attribution of 2012 and 2003-12 rainfall deficits in eastern Kenya and southern Somalia. *Bulletin of the American Meteorological Society* **94** (9): S45–S48.

Gall, E. T., Carter, E. M., Earnest, C. M. and Stephens, B. (2013). Indoor air pollution in developing countries: Research and implementation needs for improvements in global public health. *American Journal of Public Health* **103**: e67–e72.

Garland, R., Matoaane, M., Engelbrecht, E., Bopape, M.-J., *et al.* (2015). Regional projections of extreme apparent temperature days in Africa and the related potential risk to human health. *International Journal of Environmental Research and Public Health* **12** (10): 12577–12604.

Gaythorpe, K. T., Hamlet, A., Cibrelus, L., Garske, T. and Ferguson, N. M. (2020). The effect of climate change on yellow fever disease burden in Africa. *eLife* **9**: e55619.

GBD (2019). Risk Factor Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* 2020; **396**: 1223–49.

Giovannucci, D., Scherr, S. J., Nierenberg, D. and Hebebrand, C. (2012). Food and Agriculture: the future of sustainability. *The sustainable development in the 21st century (SD21) Report for Rio* 20.

Girvetz, E. H., Zganjar, C., Raber, G. T., Maurer, E. P., *et al.* (2009). Applied climate-change analysis: the Climate Wizard tool. *PLoS ONE* **4** (12), e8320.

Girvetz, E., Ramirez-Villegas, J., Claessens, L., Lamanna, C., *et al.* (2018). Future climate projections in Africa: where are we headed? Chapter 2, The Climate-Smart Agriculture Papers Investigating the Business of a Productive, Resilient and Low Emission Future. Springer.

Glantz, M. H. and Katz, R. W. (1977). When is a drought a drought? *Nature* **267** (5608): 192–193.

Goergen, G., Kumar, P. L., Sankung, S. B., Togola, A. and Tamò, M. (2016). First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. *PLoS ONE*
4 **11** (10): p.e0165632.

Goldammer, J. and Ronde, C. (2004). *Wildland Fire Management Handbook for Sub-Sahara Africa*.

Gondwe, G. (2020). Assessing the Impact of COVID-19–19 on Africa's Economic Development https://unctad.org/system/files/official-document/aldcmisc2020d3_en.pdf.

Goswami, A., Basu, S. and Sadhu, P. K. (2019). Improvement of energy efficiency and effectiveness of cooking for parabolic-type solar cooker used with activated-carbon-coated aluminium cooking pot. *Global Challenges* **3** (12): 190047.

Gray, C. and Mueller, V. (2012). Drought and population mobility in rural Ethiopia. *World Development* **40**: 134–145.

Grinspoon, P. (2020). Our planet, ourselves: Climate change and health. Harvard Health Publishing. Harvard Medical School (https://www.health.harvard.edu/blog/planet-climate-change-health-2017032911481).

Haile, G. G., Tang, Q., Leng, G., Jia, G., Wang, J., *et al.* (2020). Spatial and temporal variation of drought patterns over East Africa, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-6575, https://doi.org/10.5194/egusphere-egu2020-6575.

Hald, T., Aspinall, W., Devleesschauwer, B., Cooke, R., *et al.* (2016). World Health Organization estimates of the relative contributions of food to the burden of disease due to selected foodborne hazards: a structured expert elicitation. *PLoS ONE* **11** (1), e0145839.

Hales, S., de Wet, N., Maindonald, J. and Woodward, A. (2002). Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. *Lancet* **360**: 830–834.

Hales, S., Kovats, S., Lloyd, S. and Campbell-Lendrum, D. (2014). Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s., World Health Organization, & Health Security and Environment Cluster.

Halounova, L. and Holubec, V. (2014). Assessment of flood with regards to land cover changes. *Procedia Economics and Finance* **18**: 940–947.

Harmsen, M. J. H. M., van Dorst, P., van Vuuren, D. P., *et al.* (2020). Co-benefits of black carbon mitigation for climate and air quality. *Climatic Change* **163** (3): 1519–1538.

Hashizume, M., Armstrong, B., Hajat, S., Wagatsuma, Y., *et al.* (2007). Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups. *International Journal of Epidemiology* **36**: 1030–1037.

Hay, S. I., Cox, J., D. J., Rogers, D. J., Randolph, S. E., *et al.* (2002). Climate change and the resurgence of malaria in the East African highlands. *Nature* **415**: 905–909.

Heather, J. Z. and Aluoch, J. (2016). Advancing Lung Health in Africa, a global imperative: The Pan African Thoracic Society (PATS), https://www.ersnet.org/the-society/news/respiratory-worldwide/advancing-lung-health-in-africa,-a-global-imperative:-the-pan-african-thoracic-society-pats.

Hebe, N. G., Fiona, C., Katherine, S., Sanam, A., *et al.* (2019). Burden of non-communicable diseases in sub-Saharan Africa, 1990–2017: results from the Global Burden of Disease Study 2017.

5 Hess, C. and Macgregor, J. (2009). International Institute for Environment and Development, Policy Pointers.

Hodges, R. J., Buzby, J. C. and Bennett, B. (2011). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *Journal of Agricultural Science* **149** (S1): 37.

Hoffmann, R., Dimitrova, A., Muttarak, R., *et al.* (2020). A meta-analysis of country-level studies on environmental change and migration. *Nature Climate Change* **10**: 904–912. https://doi.org/10.1038/s41558–020–0898–6.

Holmström, K. E., Järnberg, U. and Bignert, A. (2005). Temporal trends of PFOS and PFOA in guillemot eggs from the Baltic Sea. *Environmental Science and Technology* **39**: 80–84.

Hu, X., Wu, J., Chen, P., Sun, T. and Li, D. (2017). Impact of climate variability and change on crime rates in Tangshan, China. *Science of the Total Environment* **609**: 1041–1048.

Huang, C., Barnett, A. G., Wang, X., Vaneckova, P., *et al.* (2011). Projecting future heat-related mortality under climate change scenarios: a systematic review. *Environmental Health Perspectives* **119**: 1681–1690.

IARC (2017). International Agency for Research on Cancer (2017). List of agent classified by the LARC monographs. Lyon, France. 1–105.

International Diabetes Federation (2019). International Diabetes Federation (2014): Diabetes and Climate Change Report. https://idf.org/our-network/regions-members/africa/diabetes-in-africa.html.

INRA, (2021). The United Nations University, https://inra.unu.edu/research/green-africa n-transformation-great-pathways-building-a -partnership-for-africa-eu-collaboration-on-l ow-carbon-development-bmz-project.html#outline.

IPCC (2007), Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change" (Cambridge: Cambridge University Press, 2007), 433–467.

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation—Summary for Policymakers; IPCC. New York, NY, USA: 582.

IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, and New York, NY, USA.

IPCC (2014a). Climate Change Synthesis Report. (Retrieved August 2020, from https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf.

IPCC (2018). *Special Report on the Impacts of a Global Warming of 1.5 °C.* Available online: https://www.ipcc.ch/sr15/.

IPCC (2020). Desert Locusts Could Worsen Food Insecurity in East and Horn of Africa IPCC Global Platform.

IPCC (2021). 6th Report Regional Fact Sheet Africa. https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Africa.pdf.

IUCN, Climate Change in West Africa: The Risk to Food Security and Biodiversity (Cambridge: IUCN, 2004). 6

Jacob, D. J. and Winner, D. A. (2009). Effect of climate change on air quality *Atmospheric Environment* **43**: 51–63.

Jofre, J., Blanch, A. R. and Lucena, F. (2009). *Water-borne infectious disease outbreaks associated with water scarcity and rainfall events. Water scarcity in the Mediterranean. Springer*.

Kablan, M. K. A., Dongo, K. and Coulibaly, M. (2017). Assessment of social vulnerability to flood in urban Côte d'Ivoire using the MOVE Framework. *Water* **9** (4): 292.

Kablan, N. H. J. L. (2010). Invasion des véhicule occasion en transit par le port d'Abidjan: le dynamisme ambivalent d'une activité en plein essor. *Cah. O.-m* **63**: 365–390.

Kammila, S., Kappen, J. F., Rysankova, D., Hyseni, B., *et al.* (2014). Clean and improved cooking in sub-Saharan Africa: a landscape report. The World Bank.

Kapwata, T., Gebreslasie, M. T., Mathee, A. and Caradee, W. Y. (2018). Current and Potential Future Seasonal Trends of Indoor Dwelling Temperature and Likely Health Risks in Rural

Southern Africa. *International Journal of Environmental Research and Public Health.* **15** (5): 952.

Kaser, G., Hardy, D., Molg, T. and Bradley, R. (2004). Modern glacier retreat on Kilimanjaro as evidence of climate change: observation and facts. *International Journal of Climatology* **24** (3): 329–339.

Kasye, M., Teshome, D., Abiye, A. and Eshetu, A. (2016). A review on rift valley fever on animal, human health and its impact on livestock marketing. *Austin Virology and Retrovirology* **3** (1): 1020.

Katelaris, C. H. and Beggs, P. J. (2018). Climate change: allergens and allergic diseases. *Internal Medicine Journal* **48** (2): 129–134.

Mbiyozo, A.-N. (2020). Migration: a critical climate change resilience strategy. Institute for Security Studies.

Mudie, K., Jin, M. M., Tan, L. K., Addo, J., *et al.* (2018). Non-communicable diseases in sub-Saharan Africa: a scoping review of large cohort studies. *Journal of Global Health* **9** (2): 020409.

Kinney, P. L. (2008). Climate change, air quality, and human health. *American Journal of Preventive Medicine* **35**: 459–67.

Kjellstrom, T., Lemke, B., Hyatt, O. and Otto, M. (2014). Climate change and occupational health: A South African perspective. SAMJ. *South African Medical Journal* **104** (8): 586–587.

Kjellstrom, T. and McMichael, A. J. (2013). Climate change threats to population health and well-being: the imperative of protective solutions that will last. *Global Health Action* **6**: 20816.

Kolstad, E. W. and Johansson, K. A. (2011). Uncertainties associated with quantifying climate change impacts on human health: a case study for diarrhoea. *Environmental Health Perspectives* **119** (3): 299–305.

Kumar, D. and Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods* **6** (1): 8.

Lake, I. R. and Barker, G. C. (2018). Climate change, foodborne pathogens and illness in higher income countries. *Current Environmental Health Reports* **5** (1): 187–196.

Lama, J. R., Seas, C. R., Leon-Barua, R., Gotuzzo, *et al.* (2004). Environmental temperature, cholera, and acute diarrhoea in adults in Lima, Peru. *Journal of Health, Population and Nutrition* **22**: 399–403.

Lartey, A., Hemrich, G., Amoroso, L., Remans, R., *et al.* (2016). Influencing food environments for healthy diets. Rome: Food and Agriculture Organization of the United Nations.

Laurance, W. F., Useche, D. C., Rendeiro, J., Kalka, M., *et al.* (2012): Averting biodiversity collapse in tropical forest protected areas. *Nature* **489**: 290–294.

Lawrence, A. J., Mashi, A. and Taneja, A. (2004). Indoor/Outdoor relationship of carbon monoxides and oxides of nitrogen in domestic home with roadside, urban and rural locations in a central India region. *Indoor Air* **15**: 76–82.

Le Tertre, A., Lefranc, A., Eilstein, D., Declercq, C., *et al.* (2005). Impact of the 2003 Heatwave on all-cause mortality in 9 French cities. *Epidemiology* **17** (1): 75–79.

Leclerc, H., Schwartzbrod, L. and Dei-Cas, E. (2002). Microbial agents associated with waterborne diseases. *Critical Reviews in Microbiology* **28** (4): 371–409.

Leendertz, S. A. J., Gogarten, J. F., Düx, A., Calvignac-Spencer, S. and Leendertz, F. H. (2016). Assessing the evidence supporting fruit bats as the primary reservoirs for Ebola viruses. *EcoHealth* **13**: 18–25.

Levy, K., Woster, A. P., Goldstein, R. S. and Carlton, E. J. (2016). Untangling the impacts of climate change on waterborne diseases: a systematic review of relationships between diarrheal diseases and temperature, rainfall, flooding, and drought. *Environmental Science & Technology* **50**: 4905–4922.

Levy, K., Smith, S. M. and Carlton, E. J. (2018). Climate change impacts on waterborne diseases: moving toward designing interventions. *Current Environmental Health Reports* **5** (2): 272–282.

Lewis, S. L., Edwards, D. P. and Galbraith, D. (2015). Increasing human dominance of tropical forests. *Science* **349**: 827–832.

Ligon, G. and Bartram, J. (2016). Literature review of associations among attributes of reported drinking water disease outbreaks. *International Journal of Environmental Research and Public Health* **13** (6): 527.

Lindvall, K. I., Kinsman, J., Abraha, A., Dalmar, A., *et al.* (2020). Health status and health care needs of drought-related migrants in the Horn of Africa: a qualitative investigation. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7459765/.

Liu, T., Xu, Y. J., Zhang, Y. H., Yan, Q. H., *et al.* (2013). Associations between risk perception, spontaneous adaptation behavior to heat waves and heatstroke in Guangdong province, China. *BMC Public Health* **13** (1): 913.

Liu, P. (2015). The future of food and agriculture: trends and challenges. Food and Agriculture Organization of the United Nations.

Lloyd, S., Kovats, S. and Chalabi, Z. (2014). Coastal flood mortality, in World Health Organization's 'Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s'. Geneva.

Madzwamuse, M. (2010). Climate governance in Africa: adaptation strategies and Institutions Cape Town. Heinrich Böll Stiftung South Africa.

Makoutodé C. P. (2015): Pulvérisation intra domiciliaire dans la lutte contre le paludisme dans la commune de Kouandé au Benin: analyse cout-efficacité d'une stratégie réémergente, thèse de doctorat en environnement et santé à l'UAC-Bénin, 207 p.

Marvel, K. and Bonfils, C. (2013). Identifying external influences on global precipitation. *Proceedings of the National Academy of Sciences of the United States of America* **110** (48): 19301–19306.

Masih, I., Maskey, S., Mussá, F. and Trambauer, P. (2014). A review of droughts on the African continent: a geospatial and long-term perspective. *Hydrology and Earth System Sciences* **18**: 3635–3649.

Mathee, A., Oba, J. and Rose, A. (2010). Rose. Climate change impacts on working people (the HOTHAPS initiative): findings of the South African pilot study. *Global Health Action* **3** (1): 5612.

Mbete, R. A., Banga-Mboko, H., Racey, P., Mfoukou-Ntsakala, P., *et al.* (2011). Household bushmeat consumption in Brazzaville, the Republic of the Congo. *Tropical Conservation Science* **4**: 187–202.

McMichael, A. J., Campbell-Lendrum, D., Kovats, R. S., Edwards, S., *et al*. (2004). Climate change. In: Ezzati M, Lopez AD, Rodgers A, Murray CJ, editors. *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Due To Selected Major Risk Factors*. World Health Organization. Geneva.

McMichael, A. J., Woodruff, R. E. and Hales, S. (2006). Climate change and human health: present and future risks. *The Lancet* **367** (9513): 859–869.

McMichael, A. J. (2013). Globalization, climate change and human health. *New England Journal of Medicine* **368**: 14.

Moyo, M., Mvumi, B. M., Kunzekweguta, M., Mazvimavi, K., *et al.* (2012). Farmer perceptions on climate change and variability in semi-arid Zimbabwe in relation to climatology evidence. *African Crop Science Journal* **20** (2): 317–335.

Msafiri Y Mkonda, (2019). A novel assessment of the impacts, vulnerability and adaptation of climate change in Eastern Africa. In: *Rainfall-Extremes, Distribution and Properties*. IntechOpen.

Muita, R. R., Van Ogtrop, F., Ampt, P. and Vervoort, R. W. (2016). Managing the water cycle in Kenyan small-scale maize farming systems: Part 1. Farmer perceptions of drought and climate variability. *Wiley Interdisciplinary Reviews: Water* **3** (1): 105–125.

Murphy, H. M., Pintar, K. D., McBean, E. A., Thomas, M. K. (2014). A systematic review of waterborne disease burden methodologies from developed countries. *Journal of Water Health* **12** (4): 634–655.

Nangombe, S., Tianjun, Z., Wenxia, Z., Liwei, Z. and Donghuan, L. (2019). High-temperature extreme events over Africa under 1.5 and 2 °C of global warming. *Journal of Geophysical Research: Atmospheres* **124** (8): 4413–4428.

NASAC. (2016). Climate Change Adaptation and Resilience in Africa, Nairobi. http://www.nasaconline.org/attachments/article/123/NASAC%20Strategic%20Plan%202011–2015.pdf.

NASAC. (2017). Changing Disease Patterns in Africa, Nairobi.

NASAC (2018). "Strategic Plan 2018–2022". Nairobi. http://www.nasaconline.org/attachments/article/123/NASAC%20Strategic%20Plan%20 2011–2015.pdf.

NASAC (2018a). Opportunities and challenges for research on food and nutrition security and agriculture in Africa. Available at: https://nasaconline.org/wp-content/uploads/2018/05/NASAC-FNSA-Opportunities-and-challenges-for-research-on-food-nutrition-security-and-agriculture-in-Africa.pdf. 8

Neumayer, E. and Plümper, T. (2007). The gendered nature of natural disasters: The impact of catastrophic events on the gender gap in life expectancy, 1981–2002. *Annals of the Association of American Geographers* **97**: 551–566.

Ngarakana-Gwasira, E. T., Bhunu, C. P., Masocha, M. and Mashonjowa, E. (2016). Assessing the role of climate change in malaria transmission in Africa. *Malaria Research and Treatment* **2016**: 7104291.

Nhamo, G. and Muchuru, S. (2019). Climate adaptation in the public health sector in Africa: evidence from United Nations Framework Convention on Climate Change National Communications. *Jàmbá: Journal of Disaster Risk Studies* **11**: 1–10.

Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., *et al.* (2014). "Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability". Cambridge, UK, and New York, USA: Cambridge University Press.

Nkemdirim, L. C. (2003). *Climates in Transition: Commission on Climatology*. Washington, DC: Minuteman Press.

Nofal, F. and Saeed, A. (1997). Seasonal variation and weather effects on road traffic accidents in Riyadh city. *Public Health* **111** (1): 51–55.

NRC and IDMC (2015). Global estimate: People displaced by disasters.

Nugent, R. and Fottrell, E. (2019). Non-communicable diseases and climate change: linked global emergencies. *The Lancet* **394** (10199): 622–623.

O'Lenick, C. R., Wilhelm, O. V., Michael, R. and Hayden, M. H. (2019). Urban heat and air pollution: a framework for integrating population vulnerability and indoor exposure in health risk analyses. *Science of the Total Environment* **660**: 715–723.

Obradovich, N., Migliorini, R., Paulus, M. P. and Rahwan, I. (2018). Empirical evidence of mental health risks posed by climate change. *Proceedings of the National Academy of Sciences of the United States of America* **115** (43): 10953–10958.

OCHA (2019). Situation Report, no. 18. Mozambique: Cyclone Idai and Floods.

9 Ogouwalé E. (2006). Changements climatiques dans le bénin méridional et central. Indicateurs, scénarios et prospective de la sécurité alimentaire. Thèse de doctorat; UAC/FLASH/EDP; 306 pages.

Olago, D., Marshall, M., Wandiga, S. O., Opondo, M., *et al.* (2007). Climatic, socio-economic, and health factors affecting human vulnerability to cholera in the Lake Victoria basin, East Africa. *Ambio* **36** (4): 350–358.

Olivero, J., Fa, J. E., Real, R., Márquez, A. L., *et al.* (2017). Recent loss of closed forests is associated with Ebola virus disease outbreaks. *Scientific Reports* **7**: 1–9.

Olutola (2020). Policy Briefing. Climate change and Migration (2020). Addressing the Climate-Migration Nexus in the AU-UN Partnership.

Onozuka, D., Hashizume, M., Hagihara, A. (2010). Effects of weather variability on infectious gastroenteritis. *Epidemiology & Infection* **138**: 236–243.

Orindi, A. V. (2005). Climate change and development consultation (GHACOF) on key researchable issues. 12th Greater Horn of Africa Climate Change Outlook Forum. Nairobi, Kenya.

Orru, H. (2017). The interplay of climate change and air pollution on health. *Current Environmental Health Reports* **4**: 504–513.

Osman-Elasha, B. (2009). Climate change impacts, adaptation, and links to sustainable development in Africa. *Unasylva* **60**: 12–16.

Otto, F. E., Boyd, E., Jones, R. G., Cornforth, R. J., *et al.* (2015). Attribution of extreme weather events in Africa: a preliminary exploration of the science and policy implications. *Climatic Change* **132** (4): 531–543.

Owen, N., Sparling, P. B., Healy, G. N., Dunstan, D. W., *et al.* (2010). Sedentary behavior: emerging evidence for a new health risk. *Mayo Clinic Proceedings* **85** (12): 1138–1141.

Pascual, M, Ahumada, J. A., Chaves, L. F., Rodó, X., *et al.* (2006). Malaria resurgence in the East African highlands: Temperature trends revisited. *Proceedings of the National Academy of Sciences of the United States of America* **103** (15): 5829–5834.

Parry, M. L., Carter, T. R. and Konijn, N. T. (1988). The climatology of droughts and drought prediction. In: *The Impact of Climatic Variations on Agriculture*, pp. 305–323. Springer, Dordrecht.

Pretty, J., Sutherland, W. J., Ashby, J., Auburn, J., *et al.* (2010). The top 100 questions of importance to the future of global agriculture. *International*

*Journal of Agricultural Sustainability* **8** (4): 219–236.

Prudhomme, C., Giuntoli, I., Robinson, E. L., Clark, D. B., *et al.* (2014). Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. *Proceedings of the National Academy of Sciences of the United States of America* **111** (9): 3262–3267.

Ranson, M. (2014). Crime, weather, and climate change. *Journal of Environmental Economics and Management* **67** (3): 274–302.

Rao, N., Lawson, E. T., Raditloaneng, W. N., Solomon, D., *et al.* (2019). Gendered vulnerabilities to climate change: insights from the semi-arid regions of Africa and Asia. *Climate and Development* **11** (1): 14–26.

Rigaud, K. K., de Sherbinin, A., Jones, B., Bergmann, J., *et al*. (2018): *Groundswell: Preparing for Internal Climate Migration*. World Bank.

Rippke, U., Ramirez-Villegas, J. and Jarvis, A. (2016). Timescales of transformational climate change adaptation in sub-Saharan African agriculture. *Nature Climate Change* **6** (6): 605–609.

Robert, M., Kleeman, M. and Jakober, C. (2007). Size and composition distributions of particulate matter emissions: part 2—heavy-duty diesel vehicles. *Journal of the Air & Waste Management Association* **57**: 1429–1438.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., *et al*. (2018). Mitigation pathways compatible with 1.5°C in the context of sustainable development. In *Global warming of 1.5 °C*, pp. 93–174. Intergovernmental Panel on Climate Change.

Roncoli, C., Jost, C., Kirshen, P., Sanon, M., *et al.* (2009). From accessing to assessing forecasts: an end-to-end study of participatory climate forecast dissemination in Burkina Faso (West Africa). *Climatic Change* **92** (3–4): 433.

Rother, H.-A., Sabel, C. E. and Vardoulakis, S. (2020). A collaborative framework highlighting climate-sensitive non-communicable diseases in urban sub-Saharan Africa. Africa and the Sustainable Development Goals, Springer. 267–278.

Roudier P, Sultan, B., Quirion, P. and Berg, A. (2011). The impact of future climate change on West African crop yields: what does the recent literature say? *Global Environmental Change* **21** (3): 1073–1083.

Rufat, S., Tate, E., Burton, C. G. and Maroof, A. S. (2015). Social vulnerability to floods: Review of case studies and implications for measurement. *International Journal of Disaster Risk Reduction* **14**: 470–486.

Rulli, M. C., Santini, M., Hayman, D. T. and D'Odorico, P. (2017). The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks. *Scientific Reports* **7**: 41613.

Sacks E, Sonam Yangchen Robert Marten (2021). COVID-19–19, climate change, and communities. *The Lancet Planetary Health* **5** (10): e663.

Scheffran, J., Link, P. M. and Schilling, J. (2019). Climate and conflict in Africa. *Oxford Research Encyclopedia of Climate Science*.

SciDevNet. Africa's Science Research Output Doubles in a Decade. SciDevNet R&D News. [Online] November 3, 2014. https://www.scidev.net/sub-saharan-africa/r-d/news/research-output-doubles.html.

Schijven, J., Bouwknegt, M., de Roda Husman, A. M., Rutjes, S., *et al.* (2013). A decision support tool to compare waterborne and foodborne infection and/or illness risks associated with climate change. *Risk Analysis* **33** (12): 2154–2167.

Schnell, J. L. and Prather, M. J. (2017). Co-occurrence of extremes in surface ozone, particulate matter, and temperature over eastern North America. *Proceedings of the National Academy of Sciences of the United States of America* **114** (11): 2854–2859.

Scovronick, N., Sera, F., Acquaotta, F., Garzena, D., *et al.* (2018). The association between ambient temperature and mortality in South Africa: a time-series analysis. *Environmental Research* **161**: 229–235.

Shepard D. (2019). Global warming: severe consequences for Africa. New report projects greater temperature increases. *Africa Renewal* **32** (3): 34.

Shindell, D., J. Kuylenstierna, Vignati, E., R. van Dingenen, *et al.* (2012). Simultaneously mitigating near-term climate change and improving human health and food security. *Science* **335** (6065): 183–189.

Shultz, J. M., Russell, J. and Espinel, Z. (2005). Epidemiology of tropical cyclones: the dynamics of disasters, disease, and development. *Epidemiologic Reviews* **27**: 21–35.

Sillmann, J., Kharin, V. V. and Zhang, X. (2013). Climate extremes indices in the CMIP5 multimodel ensemble: part 1. Model evaluation in the present climate. *Journal of Geophysical Research: Atmospheres* **118**: 1716–1733.

Simelton, E., Quinn, C. H., Batisani, N., Dougill, A. J., *et al.* (2013). Is rainfall really changing? Farmers' perceptions, meteorological data, and policy implications. *Climate and Development* **5** (2): 123–138.

Siraj, A. S., Santos-Vega M., Bouma, M. J., Yadeta, D., *et al.* (2014). Altitudinal changes in malaria incidence in highlands of Ethiopia and Colombia. *Science* **343**: 1154–1158.

Smith, K., Woodward, A., D. Campbell-Lendrum, Chadee, D., *et al.* (2014). WGII IPCC 5th Report. Human health: impacts, adaptation, and co-benefits. Climate change 2014: impacts, adaptation, and vulnerability: global and sectoral aspects. Cambridge, UK: Cambridge University Press.

Sobczak-Szelc, K., Fekih, N. (2020). Migration as one of several adaptation strategies for environmental limitations in Tunisia: evidence from El Faouar. *Comparative Migration Studies* **8**: 8. https://doi.org/10.1186/s40878-019-0163-1.

Solomon, S. (2007). The physical science basis: Contribution of WG1 IPCC 4th Report (IPCC), Climate change 2007: 996.

Sotoudehnia, F. and Comber, A. (2010). Poverty and environmental justice : A GIS analysis of urban greenspace accessibility for different economic groups. Proceedings of the 13th AGILE Int Conf on Geographic Information Science, Guimaraes, Portugal.

Sultan B., Roudier, P. and Traoré, S. (2014). The impacts of climate change on crop yields in West Africa. In: *Rural Societies in the Face of Climatic and Environmental Changes in West Africa* (eds Sultan, B., *et al*.), pp. 199–214. https://books.openedition.org/irdeditions/12352?lang=en.

Sylla, M. B., Faye, A., Giorgi, F., Diedhiou, A. and Kunstmann, H. (2018). Projected heat stress under 1.5 °C and 2 °C global warming scenarios creates unprecedented discomfort for humans in West Africa. *Earth's Future* **6**: 1029–1044.

Tear Fund. (2010). "Caring for the environment and the people, in Footsteps". Teddington, UK: Tear Fund.

Thiam, S., Diène, A.N., Sy, I., Winkler, M.S., *et al.* (2017). Association between childhood diarrhoeal incidence and climatic factors in urban and rural settings in the health district of Mbour, Senegal. *International Journal of Environmental Research and Public Health* **14** (9): 1049. 10

Thomas, C. J., Davies, G. and Dunn, C. E. (2004): Mixed picture for changes in stable malaria distribution with future climate in Africa. *Trends in Parasitology* **20**: 216–220.

Tian, J., Bryksa, B. C. and Yada, R. Y. (2016). Feeding the world into the future–food and nutrition security: the role of food science and technology. *Frontiers in Life Science* **9** (3): 155–166.

Tirado, M., Clarke, R., Jaykus, L., McQuatters-Gollop, A. and Frank, J. M. (2010). Climate change and food safety: a review. *Food Research International* **43** (7): 1745–1765.

Turner, I. M. (1996). Species loss in fragments of tropical rain forest: a review of the evidence. *Journal of Applied Ecology* **33**: 200–209.

UNDP (2015). Africa Adaptation Programme: https://www.undp.org/publications/africa-adaptation-programme.

UNECA (2011) United Nations Economic Commission for Africa. Climate change and health across Africa: issues and options, African Climate Policy Centre, Working paper 20.

UNEP (2017). United Nations Environment Programme. Diesel Fuel Sulphur Levels: Global Status. (Retrieved 27 May 2018), from http://www.unep.org/transport/PCFL.

UNEP (2020). United Nations Environment Programme. Preventing the next pandemic: Zoonotic diseases and how to break the chain of transmission. https://wedocs.unep.org/bitstream/handle/20.500.11822/32316/ZP.pdf?sequence=1&isAllowed=y. [Accessed 26 July 2020].

UNEP. (2020a) United Nations Environment Programme. Regional initiatives: Responding to climate change. 2020 (Retrieved 27 July 2020, from https://www.Unenvironment.Org/regions/africa/regional-initiatives/responding-climate-change.

UNESCO (2010). Global environmental change and food security. UNESCO-SCOPE-UNEP Policy Brief no. 12.

UNFCCC (2015). Key aspects of the Paris Agreement accessed https://UNFCCC.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement.

UNFCCC (2020). Climate Change Is an Increasing Threat to Africa, https://UNFCCC.int/news/climate-change-is-an-increasing-threat-to-africa.

USEPA (2014). Climate Change Indicators in the US, Report.

USEPA (2014a). Introduction to Indoor Air Quality. (Retrieved 27th June, 2020), from https://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality.

Van Wesenbeeck, C. F., Sonneveld, B. G. and Voortman, R. L. (2016). Localization and characterization of populations vulnerable to climate change: two case studies in sub-Saharan Africa. *Applied Geography* **66**: 81–91.

Von Schirnding, Y., Bruce, N., Smith, K., *et al.* (2002). *Addressing the Impact of Household Energy and Indoor Air Pollution on the Health of Poor: Implications for Policy Action and Intervention Measures*. Geneva: World Health Organization.

Wang, Y. and Hopke, P. K. (2013). A ten-year source apportionment study of ambient fine particulate matter in San Jose, California. *Atmospheric Pollution Research* **4** (4): 398–404.

11 Wanjiru, H. (2018). Role Of International Non-Governmental Organizations In The Adaptation And Mitigation Of Climate Change By Vulnerable Groups In East Africa. Case Study, Kenya; 2000–2016, University of Nairobi.

Watts, N., Amann, M., S. Ayeb-Karlsson, Belesova, K., *et al.* (2017). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. *The Lancet* **391**: 581–630.

Watts, N., Adger, W. N. and P. Agnolucci (2015). Health and climate change: policy responses to protect public health. *The Lancet*.

Weber, T., Haensler, A., Rechid, D., Pfeifer, S., *et al.* (2018). Analyzing regional climate change in Africa in a 1.5, 2, and 3 C global warming world. *Earth's Future* **6** (4): 643–655.

World Bank (2013). 4° Turn down the heat: Climate Extremes, Regional Impacts, and the Case for Resilience. Washington: 254.

World Bank (2017). The World Bank Annual Report 2017. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/27986 License: CC BY-NC-ND 3.0 IGO.

World-Grain (2020). Locusts Devastating Cropland in East Africa. articles/13319–locusts-devastating-cropland-in-east-africa?v=preview. https://www.world-grain.com/ articles/13319–locusts-devastating.

WHO (1987). Indoor air quality: organic pollutants. Report on a WHO meeting. Euro reports and studies. 1989; Copenhagen, World Health Organization Regional office for Europe. Berlin. 111.

WHO (2002). World Health Report https://www.who.int/publications/i/item/9241562072.

WHO (2003). Climate change and human health: risks and responses. https://www.who.int/health-topics/drought.

WHO (2008), Closing the gap in a generation: health equity through action on the social determinants of health. Commission on Social Determinants of Health. Geneva.

WHO (2012). Sahel Food and Health Crisis, West Africa Health Working Group: Emergency Health Strategy. Available at https://reliefweb.int/sites/reliefweb.int/files/resources/sahel_health_strategy_21june2012rev.pdf. [Accessed 26 July 2020].

WHO (2013). Protecting health from climate change: vulnerability and adaptation assessment. World Health Organization.

WHO (2014). Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva. Accessed, July, 2021), from https://apps.who.int/iris/handle/10665/134014.

WHO (2015). WHO Estimates of the Global Burden of Foodborne Diseases. Available online https://www.who.int/foodsafety/publications/foodborne_disease/fergreport/en/.

WHO (2015a). Facts sheet on Food Safety. Available online: https://www.who.int/en/news-room/fact-sheets/detail/food-safety.

WHO Regional Office for Africa (2015b). Continental challenges &change: environmental determinants of health in Africa: second synthesis report on the situation analysis and needs assessments for the implementation of the Libreville declaration on health and environment in Africa, January 2015. https://apps.who.int/iris/handle/10665/177155.

WHO (2015c). Effects of climate change on the social and environmental determinants of health in Africa. WHO Reginal Office for Africa: COP21/CMP 11– Paris, France.

WHO (2016). Preventing Disease through Healthy Environments: A Global Assessment of the Burden of Disease from Environmental Risks.

WHO (2016a) Atlas of Region Health Statistics accessed at https://apps.who.int/iris/handle/10665/206547.

WHO (2017). Inheriting a Sustainable World? Atlas on Children's Health and the Environment. Available online: http://apps.who.int/iris/bitstream/10665/254677/1/9789241511773–eng.pdf.

WHO (2017a). Wildfires accessed on 20/03/2022 at https://www.who.int/health-topics/wildfires#tab=tab_1.

WHO (2018). A global strategy to Eliminate Yellow fever Epidemics 2017–2026. Geneva.

WHO (2018a). Foodborne Diseases in WHO African Region – Fact Sheet. http://www.who.int/foodsafety/areas_work/foodborne-diseases/infographics_afro_en.pdf.

WHO (2019). Rift Valley Fever, fact sheet: https://www.who.int/news-room/fact-sheets/detail/rift-valley-fever.

WHO (2020). Topics: Air Pollution. Available at https://www.afro.who.int/health-topics/air-pollution. [Accessed 26 July 2020].

WHO (2020a). Health topics: Infectious diseases. Available at https://www.who.int/topics/infectious_diseases/en/. [Accessed 26 July 2020].

WHO (2021). Non-Communicable Diseases at https://www.who.int/health-topics/noncommunicable-diseases#tab=tab_1.

Wright, C. Y., Garland, R. M., Norval, M. and Vogel, C. (2014). Human health impacts in a changing South African climate. *South African Medical Journal* **104**: 579–82. 12

Wyon, D. P., Wyon, I. and Norin, F. (1996). Effects of moderate heat stress on driver vigilance in a moving vehicle. *Ergonomics* **39**: 61–75.

Wolch, J. R., Byrne J. and Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape and Urban Planning* **125**: 234–244.

Wiedinmyer, C., Yokelson, R. and Gullett, B. (2014). Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste. *Environmental Science & Technology* **48** (16): 9523–9530.

WMO (2020). (Retrieved 20th June, 2020), from https://public.wmo.int/en/our-mandate/focus-areas/natural-hazards-and-disaster-risk-reduction/tropical-cyclones.

Wu, X. (2016). Impact of climate change on human infectious diseases: empirical evidence and human adaptation. *Environment International* **86**: 14–23.

## THE NETWORK OF AFRICAN SCIENCE ACADEMIES (NASAC)

NASAC is an independent consortium of African science academies, whose main goal is to offer authoritative credible advice for policy formulation towards economic, social and cultural development on the continent.

As at April 2022, the following academies constituted the membership of NASAC:

1. **African** Academy of Sciences (AAS)
2. **Algerian** Academy of Science and Technology (AAST)
3. Académie Nationale des Sciences, Arts et Lettres du **Bénin** (ANSALB)
4. **Botswana** Academy of Sciences (BAS)
5. Académie Nationale des Sciences du **Burkina** (ANSB)
6. **Burundi** Academy of Sciences and Technology (BAST)
7. **Cameroon** Academy of Sciences (CAS)
8. Académie Nationale des Sciences et Technologies du **Congo** (ANSTC)
9. Académie des sciences, des arts, des cultures d'Afrique et des diasporas africaines, **Cote d'Ivoire** (ASCAD)
10. Academy of Scientific Research and Technology, **Egypt** (ASRT) – *Provisional Member*
11. **Ethiopian** Academy of Science (EAS)
12. **Ghana** Academy of Arts and Sciences (GAAS)
13. **Kenya** National Academy of Sciences (KNAS)
14. **Madagascar's** National Academy of Arts Letters and Sciences
15. **Mauritius** Academy of Science and Technology (MAST)
16. Hassan II Academy of Science and Technology in **Morocco**
17. Academy of Sciences of **Mozambique** (ASM)
18. **Nigerian** Academy of Science (NAS)
19. **Rwanda** Academy of Sciences (RAS)
20. Académie des Sciences et Techniques du **Sénégal** (ANSTS)
21. Academy of Science of **South Africa** (ASSAf)
22. **Sudanese** National Academy of Science (SNAS)
23. **Tanzania** Academy of Sciences (TAS)
24. Académie Nationale Des Sciences, Arts Et Lettres du **Togo** (ANSALT)
25. **Tunisia** Academy of Sciences Arts and Letters
26. **Uganda** National Academy of Sciences (UNAS)
27. **Zambia** Academy of Sciences (ZaAS)
28. **Zimbabwe** Academy of Sciences (ZAS)

NASAC Secretariat
Miotoni Lane, Off Miotoni Road
Karen, Nairobi, Kenya
Tel: +254 0712 914285
Email: nasac@nasaconline.org
Web: nasaconline.org/

SPONSORED BY THE
Federal Ministry of Education and Research

SUSTAINABLE DEVELOPMENT GOALS