

Textbook

for Climate Change
and Health In-Person Lecture Series



Erasmus+



CLIMATEMED

Project CLIMATEMED – 2024



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the European Union**

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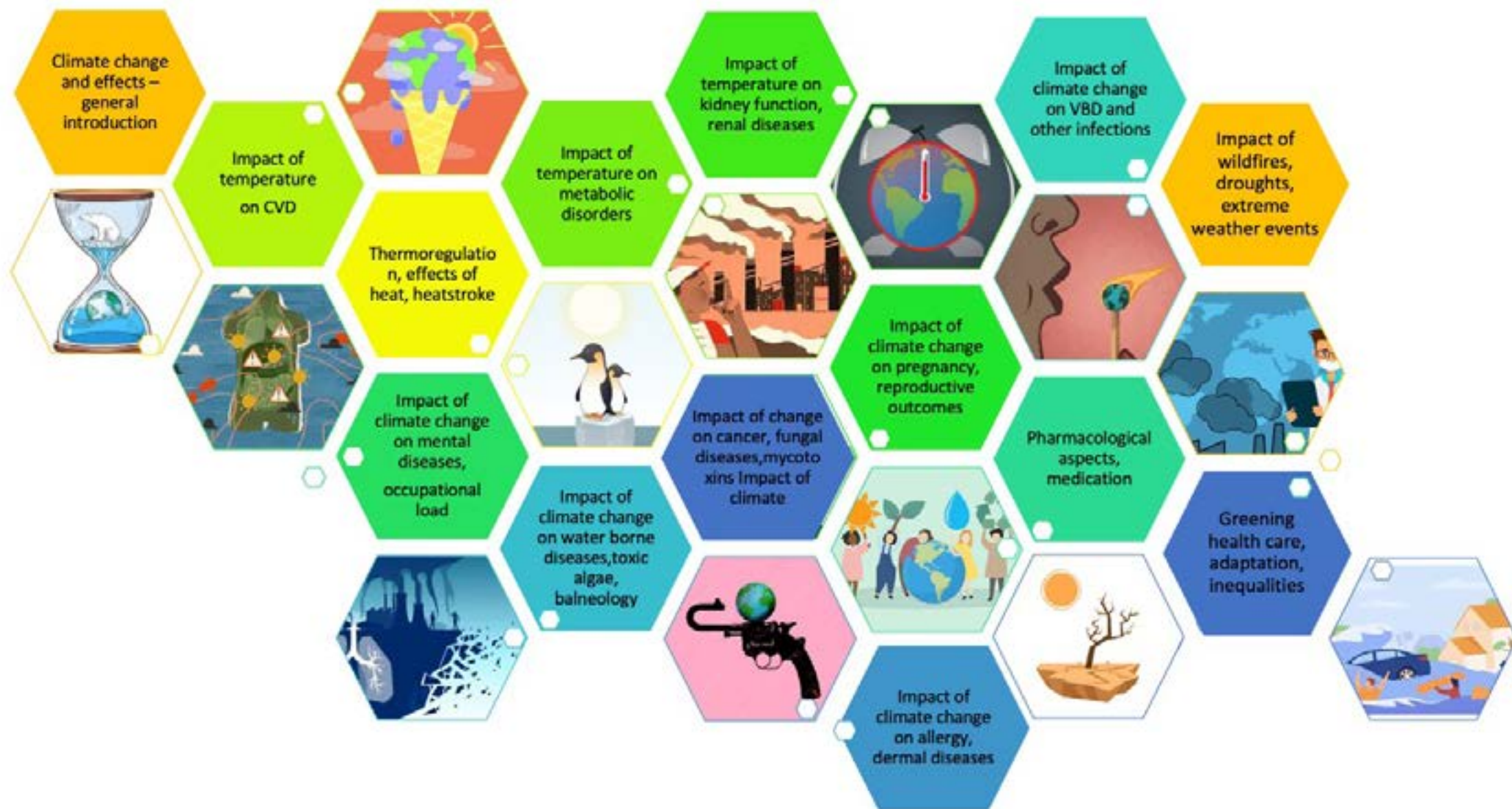
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Climate change and effects – a general introduction



Learning outcomes

Upon successful completion of the course, students will be able to:

- become familiar with general knowledge about climate change and the causes of global warming
- analyze the sensitive population groups, the most endangered persons
- acquire knowledge about the direct, indirect and tertiary impacts of climate change on human health
- study regional impacts and climate-related hazards to health
- learn about the main health topics related to climate change and thus develop a sensitivity to further study the health effects of climate change

Content of Climate change and effects - general introduction

1. Glossary
2. Introduction
3. Vulnerable populations
4. Direct, indirect and tertiary impacts of climate change on human health
5. Regional impacts
6. Climate-related hazards to health
7. Climate-sensitive diseases
and climate-sensitive health outcomes



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human activities altering the atmospheric composition, and climate variability attributable to natural causes.

- Climate change hazard - Process, phenomenon or human activity that may cause loss of life, injury or other health impact, property damage, social or economic disruption, or environmental degradation.
- Climate change risk - Potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services) and infrastructure.
- Anthropogenic climate change - climate change with the presumption of human influence, usually warming
- Global warming (GW) -usually: the warming trend over the past century or so; also: any period in which the temperature of the Earth's atmosphere increases; also the theory of such changes.

→ <https://unfccc.int>
Accessed 16 March 2023



<https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health> Accessed 29 June 2023

Climate change is a “change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”.

Source: United Nations Framework Convention on Climate Change
<https://unfccc.int/> Accessed 16 March 2023

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Climate change is one of the greatest challenges of our time. It is now widely recognized that climate change and biodiversity loss are interconnected, and that both are increasingly influenced by human activity. With our educational series we want to draw attention to a number of risks posed to human societies by the degradation of the earth's ecological and climatic systems, including threats to water and food security, air quality, the availability of natural resources used for medicinal, spiritual or recreational purposes and livelihoods, population displacement, conflict and disasters, and potential influences on patterns of disease.

- Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions, or persistent anthropogenic changes in the composition of the atmosphere or land use.
- Article 1 of the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”.
- UNFCCC thus makes a distinction between climate change attributable to

“We are on the brink of missing the opportunity to limit global warming to 1.5°C.”

UN Emissions Gap Report, 2019



“Climate change is the single biggest risk that exists to the economy today.”

Henry Paulson,
Former United States Secretary of the Treasury



The Intergovernmental Panel on Climate Change (IPCC) has concluded that to avert catastrophic health impacts and prevent millions of climate change-related deaths, the world must limit temperature rise to 1.5°C. Past emissions have already made a certain level of global temperature rise and other changes to the climate inevitable. Global heating of even 1.5°C is not considered safe, however; every additional tenth of a degree of warming will take a serious toll on people’s lives and health.

While no one is safe from these risks, the people whose health is being harmed first and worst by the climate crisis are the people who contribute least to its causes, and who are least able to protect themselves and their families against it - people in low-income and disadvantaged countries and communities.

→ doi.org/10.4337/9781788974912.1.50

↳ [Solomon B: Intergovernmental Panel on Climate Change \(IPCC\)](#)

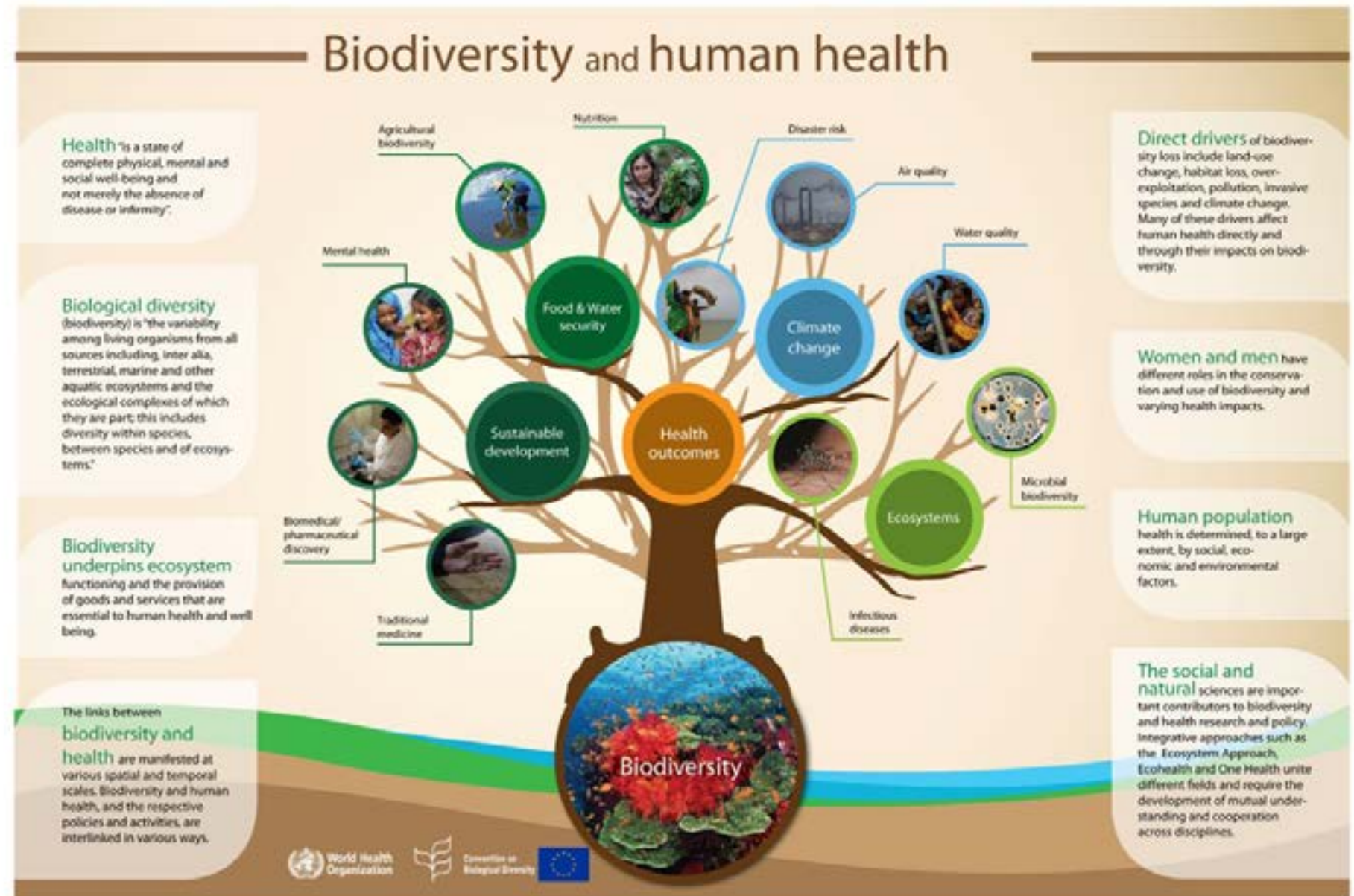


https://www.cdc.gov/climateandhealth/images/climate_change_health_impacts Accessed 16 March 2023

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<https://www.cbd.int/health/images/infographic-sok-health.png>, Accessed 16 March 2023

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- The links between biodiversity and health are manifested at various spatial and temporal scales.
- At a planetary scale, ecosystems and biodiversity play a critical role in determining the state of the Earth System, regulating its material and energy flows and its responses to abrupt and gradual change.

→ At a more intimate level, the human microbiota the symbiotic microbial communities present on our gut, skin, respiratory and urino-genital tracts, contribute to our nutrition, can help regulate our immune system, and prevent infections.

- <https://www.cbd.int/health/SOK-biodiversity-en.pdf>
p. 15, Accessed 16 March 2023

Key sectors (non-exhaustive) with relevance to health, environment and climate change



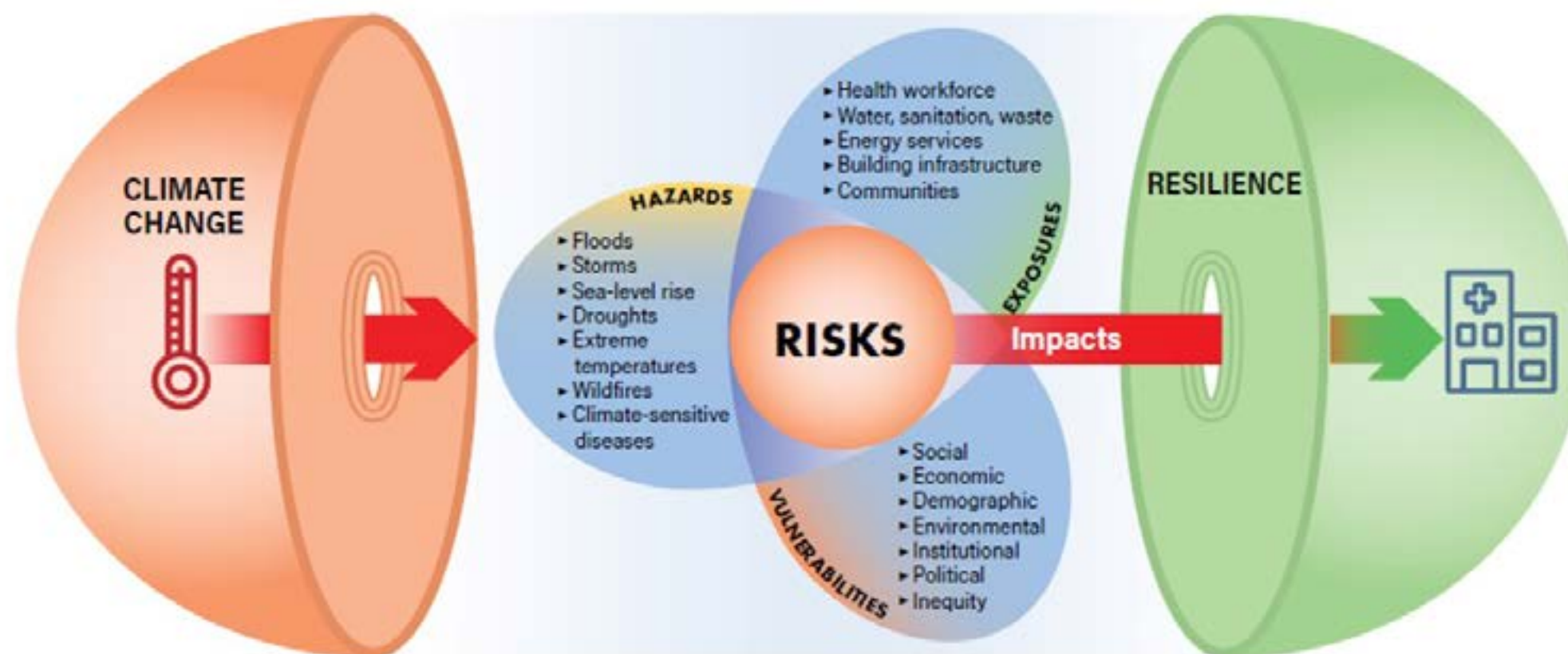
https://www.who.int/docs/default-source/climate-change/who-global-strategy-on-health-environment-and-climate-change-a72-15.pdf?sfvrsn=20e72548_2 – p. 6, Accessed 20 June 2023

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Impacts of climate-related risks on health care facilities

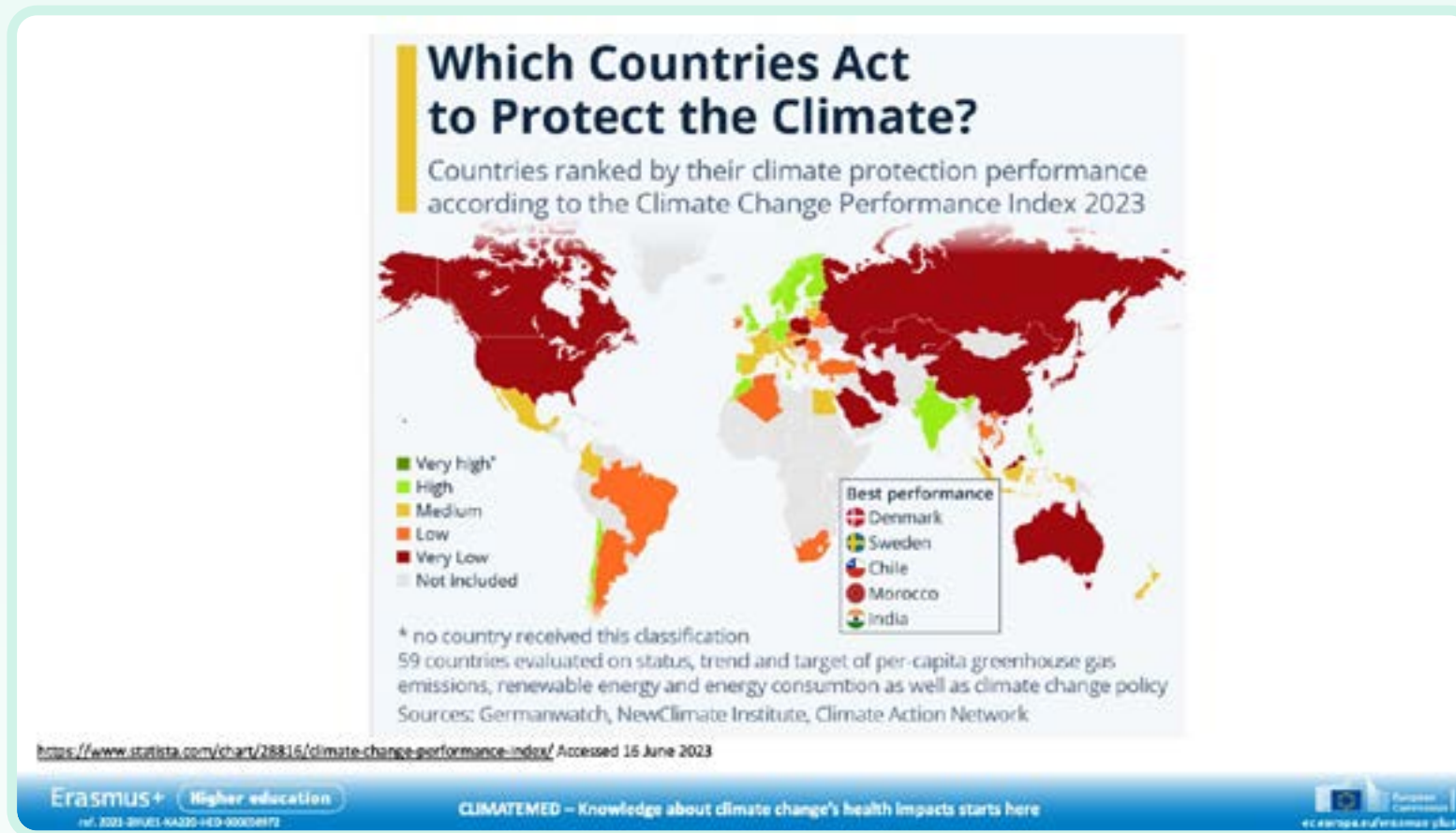


World Health Organization, Checklists to assess vulnerabilities in health care facilities in the context of climate change, ISBN 978-92-4-002290-4 (electronic version) – p. 7.

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→ Areas with weak health infrastructure – mostly in developing countries – will be the least able to cope without assistance to prepare and respond.

→ Reducing emissions of greenhouse gases through better transport, food and energy-use choices can result in improved health, particularly through reduced air pollution.

Compendium of WHO and other UN guidance on health and environment, 2022 update. Geneva: World Health Organization; 2022 (WHO/HEP/ECH/EHD/22.01)

→ <https://www.who.int/teams/environment-climate-change-and-health>
 ↳ Accessed 20 June 2023

→ Climate change is already impacting health in a myriad of ways, including by leading to death and illness from increasingly frequent extreme weather events, such as heat waves, storms and floods, the disruption of food systems, increases in zoonoses and food-, water- and vector-borne diseases, and mental health issues. Furthermore, climate change is undermining many of the social determinants for good health, such as livelihoods, equality and access to health care and social support structures.

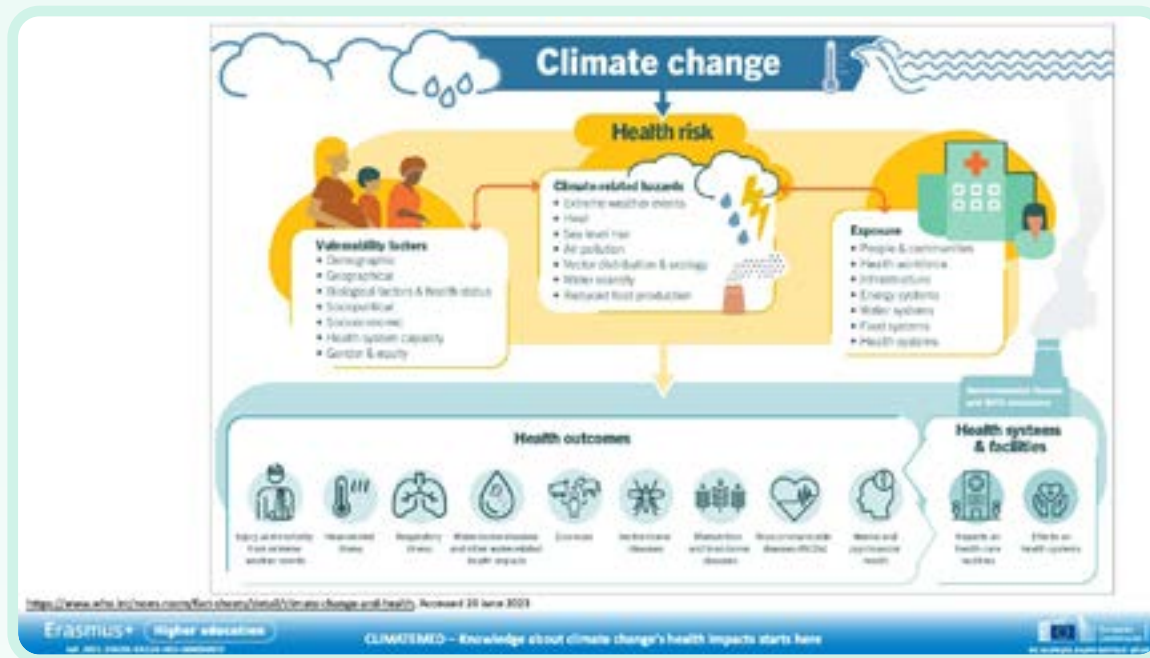
→ These climate-sensitive health risks are disproportionately felt by the most vulnerable and disadvantaged, including women, children, ethnic minorities, poor communities, migrants or displaced persons,

older populations, and those with underlying health conditions.

→ Climate change impacts health both directly and indirectly, and is strongly mediated by environmental, social and public health determinants.

→ It threatens the essential ingredients of good health – clean air, safe drinking water, nutritious food supply and safe shelter – and has the potential to undermine decades of progress in global health.

→ Between 2030 and 2050, climate change is expected to cause approximately 250 000 additional deaths per year, from malnutrition, malaria, diarrhoea and heat stress.



Vulnerable populations

Geography: Inhabitants of low-lying coastal settlements, socially and economically disadvantaged rural populations reliant on subsistence farming and with poorer access to services, and outdoor workers in countries with hot climates are more likely to experience health effects. Regions of Asia and Africa are projected to experience 85 to 95% of the global exposure to multi-sector risks (including risks to water, energy and land sectors, such as drought intensity and water stress, cooling demand change and heat wave exposure, habitat degradation, and crop yields)

Indigenous Identity: Climate change poses greater risks of health effects to Indigenous peoples who depend heavily on local resources and live in parts of the world where the climate is changing quickly such as Inuit populations in the Canadian Arctic.

Socioeconomic Status: The poorest countries and regions within them are most susceptible to the health effects of climate change; the socioeconomically poorest individuals living in a population experience the greatest risks during heat waves, flooding, and tropical cyclones.

Current Health Status: Populations with a high prevalence of conditions such as diabetes, ischaemic heart disease, and HIV) will be at more sensitive to health effects. Populations exposed to baseline levels of

pathogens and parasites such as dengue virus (dengue fever) and plasmodium (malaria) will be at greater risk of outbreaks following flooding events.

Age: Children are physiologically more susceptible to undernutrition, diarrhea, malaria, and dengue fever. Households with children are likelier to have a lower than average income, rendering children more susceptible to food insecurity. Older people are often less physiologically able to respond to stressors like heat and air pollution, and tend to experience greater risks during extreme events, due to their poorer mobility and limited ability to extricate themselves from hazardous situations.

Gender: Women and girls can be at greater risk for the health effects of climate change due to lower socioeconomic status and limitations imposed by gender roles. In many countries, women and girls have lower baselines of nutrition, and experience greater risk of poor nutrition during periods of food scarcity. In developed countries, males are at greater risk of fatality due to flooding. However, females face a greater risk in developing countries, where the overall risk of flooding fatality is higher. During heat waves, working age men experience high risk of health effects due to higher numbers in manual work, although women of all ages maybe at greater risk during heat waves overall.

Access to Health Care and Services: Populations with poorer access to health care and services have generally poorer climate resilience. Reduced health care and services capacity in the wake of natural hazard events can enable the resurgence of climate-sensitive infectious diseases.

→ <https://chasecanada.org/wp-content/uploads/2021/01/Climate-Change-Toolkit-for-Health-Professionals-Full-Toolkit.pdf>

↘ Accessed 16 June 2023

40 % of households around the world lack handwashing facilities.

7 million people die each year from air pollution.

More than 50 % of the world's population lives in cities.

Multiple vulnerabilities increase the risk of health impacts:

Vulnerable populations



The less abled, pregnant, or already infirm



The poor, displaced, and homeless



Children & the elderly



Athletes



Outdoor & manual workers

Many human activities put pressure on the natural environment and increase the risk that new diseases will emerge.



Poor nutrition is a major cause of ill health.

USD 400

billion is spent on subsidizing fossil fuel use.

<https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health>. Accessed 20 June 2023
<https://www.who.int/teams/environment-climate-change-and-health/climate-change-and-health/advocacy-partnerships/manifesto-infographics>

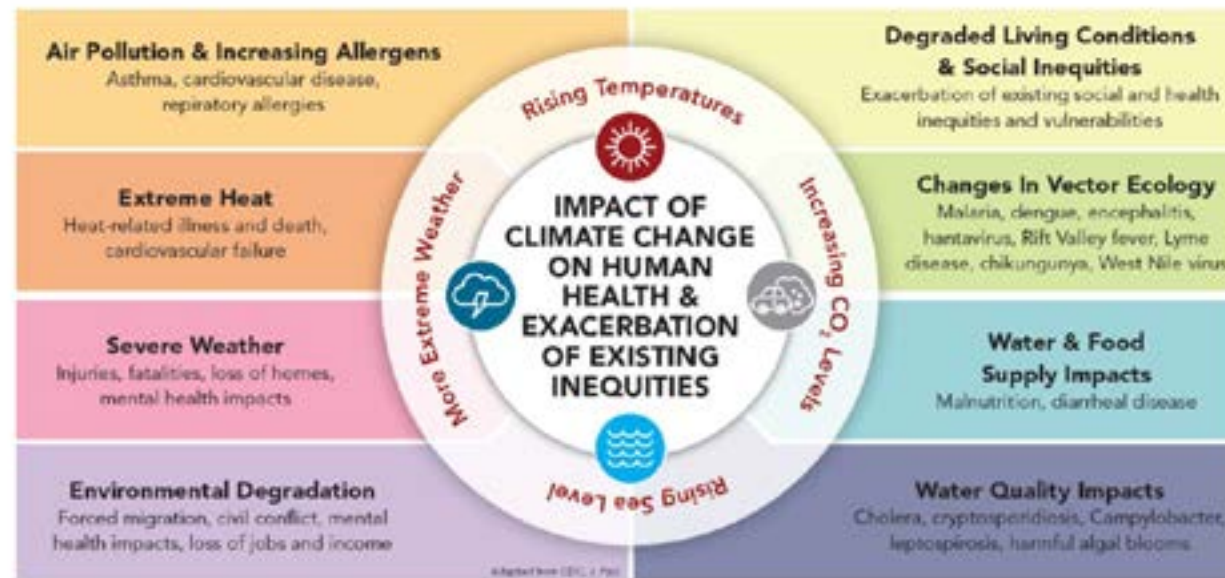
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Impacts of climate change on human health: direct, indirect and tertiary impacts



Heat and heat waves also affect the labour capacity of sectors of the economy such as agriculture, industry, and services.

The health impact of a heatwave depends on the intensity and duration of the temperature, the acclimatization and adaptation of the population, and the infrastructure and preparedness.

People with chronic diseases that take daily medications have a greater risk of complications and death during a heatwave, as do older people and children.

Reactions to heat depends on each person's ability to adapt and serious effects can appear suddenly. This is why it is important to pay attention to the alerts and recommendations of local authorities.

Direct health impacts are those that are directly, causally attributable to climate change and/or climate variability, such as cardiovascular risk associated with heat waves, or risk of injury associated with more intense and frequent storms.

Indirect health impacts arise as downstream effects of climate change and variability. These impacts are broad and variable in their etiology, such as change in infectious disease vector distribution and air pollution interacting with heat waves.

The third – “tertiary impacts” – category is, by a number of magnitudes, the most important health risk associated with climate change. These include the health impacts of large-

scale famine, forced migration and human conflict, which result from the geophysical and ecological consequences of climate change, including the alteration of ecosystems, sea-level rise, and long term disruptions in water supply and food production.

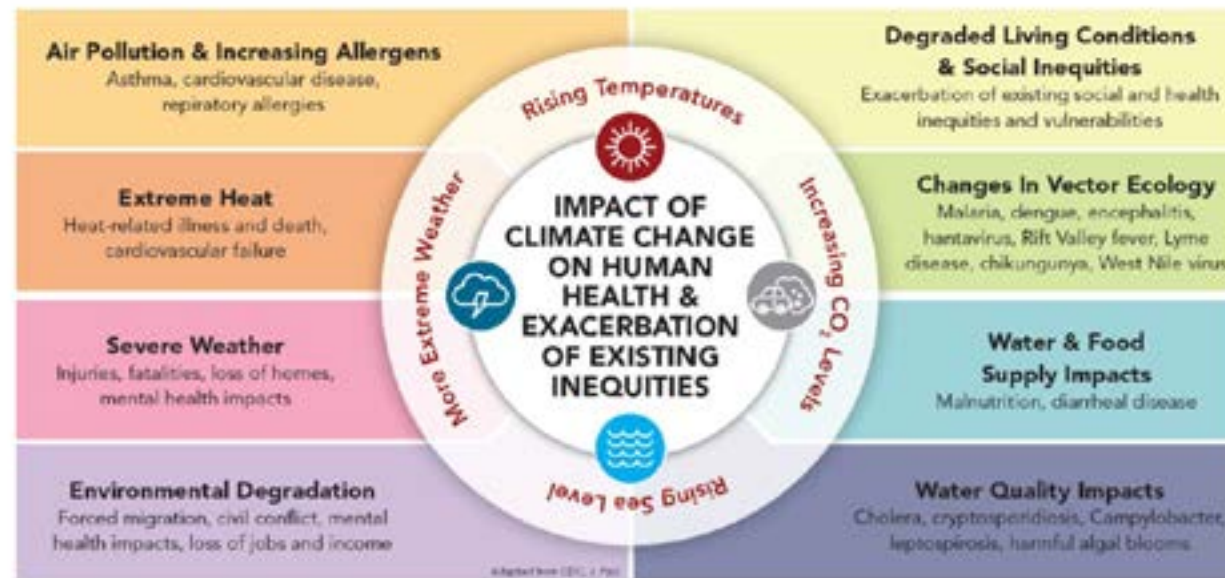
Direct health impacts:

Heat exposure can have a direct effect on population-level morbidity and mortality, due to increases in heat-related illnesses (heat exhaustion and heat stroke) and greater risk of cardiovascular, respiratory, and renal disease. Both high temperatures and heat waves are associated with more hospital admissions for mental illness, and increased risk of suicide.

Cold exposure: Although cold-related health exposures are projected to decrease with global warming, increases in heat-related morbidity and mortality will far outweigh any benefits from these reductions at the global level

Floods and storms: linked to climate change can adversely affect human health by damaging health services and other infrastructure; accelerating the spread of infectious diarrheal, leptospirosis, and vector-borne diseases; increasing the incidence of injuries, drowning, and hypothermia; and impacting mental health.

Impacts of climate change on human health: direct, indirect and tertiary impacts



maximum temperatures. It is uncertain how the rate skin cancers will be affected by climate change in the future

Food- and water-borne infectious diseases:

Diarrheal and enteric disease transmissions are affected by changes in temperature and rainfall, with studies indicating that higher temperatures and water scarcity increase diarrheal diseases of all causes.

Climate change may influence the growth, survival, persistence, transmission, and/or virulence of certain pathogens by affecting the local ecosystem capacity to act as a reservoir for species as vectors of animal-borne diseases.

Vector-borne Diseases: The spread of vector-borne diseases (including malaria, dengue fever, West Nile virus, and Lyme disease) is influenced by temperature, rainfall, flooding, economic development, and public health programs. For example, economic development and public health programs can decrease the risk of malaria and dengue fever, however, in most cases, climate change will increase the risk.

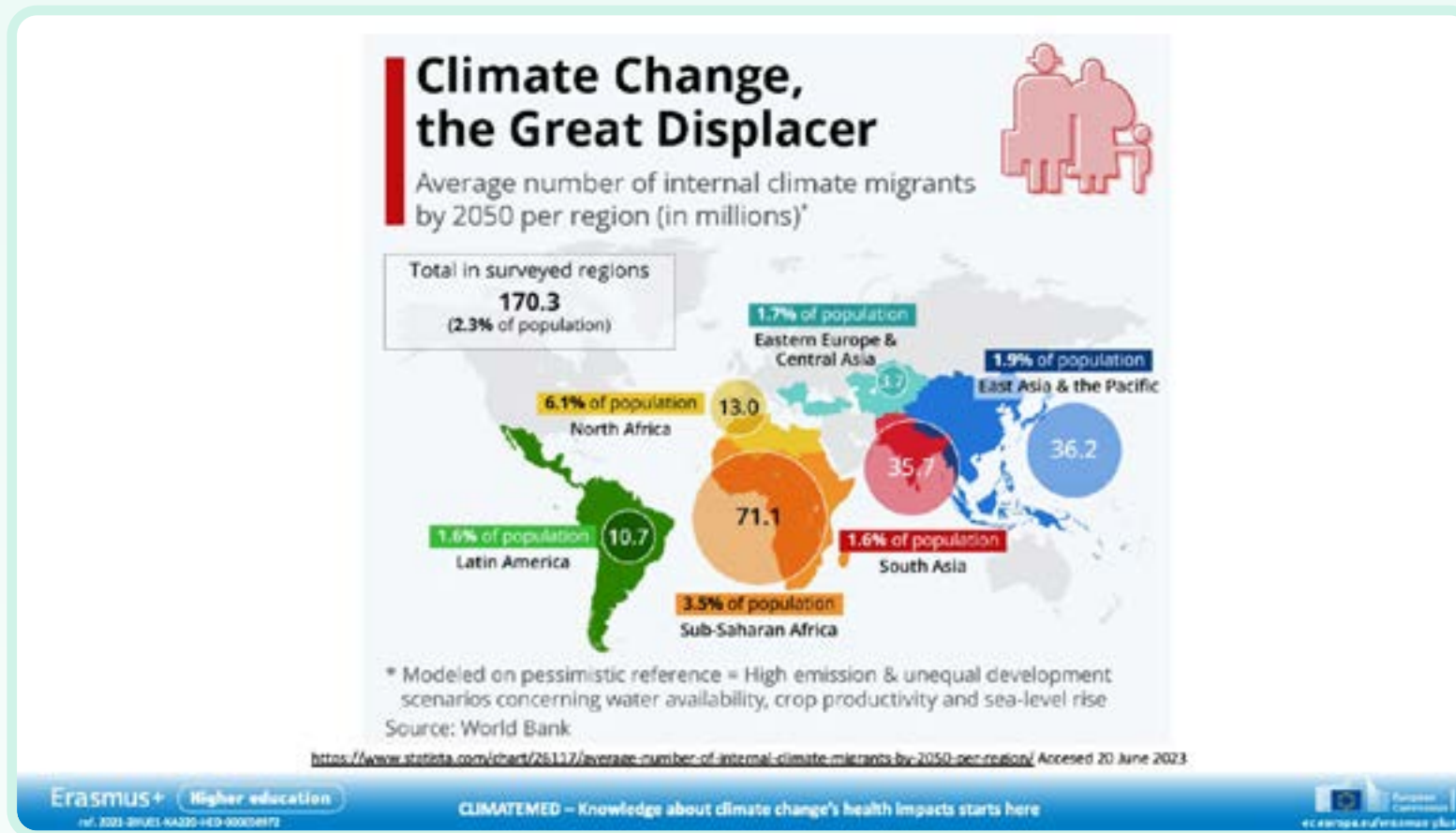
Indirect impacts

Air pollution: is estimated to cause seven million premature deaths per year globally. The majority of air pollution produced by human activity is due to the combustion of fuels for electricity, cooking, heating, transportation, industrial and agricultural processes. Since these activities additionally produce greenhouse gases (GHG) emissions, climate change and air pollution are inextricably linked. Climate change affects the level of air pollution as higher temperatures increase the number of reactions giving rise to ground-level ozone in the atmosphere. Warmer conditions can increase the production and release of airborne allergens (such as fungal spores and plant pollen) and higher carbon dioxide (CO₂) levels

can stimulate growth of these plants. Increases in airborne allergens could trigger asthma and other allergic respiratory diseases.

Wildfires: Extreme wildfires are predicted to increase in many parts of the world as a result of climate change. These events can lead to acute deaths due to burns and trauma, the need for emergent evacuation of healthcare structures and insomnia and post-traumatic-stress disorder symptoms in survivors of evacuations. Smoke can produce extremely high levels of air pollution.

Ultraviolet Radiation: The incidence and prevalence of non-melanoma skin cancers and cataract-related eye diseases are linked to levels of ultraviolet (UV) radiation and summertime



Tertiary impacts

Livelihoods and Poverty: heat can have large effects on labour capacity, particularly in agriculture. Other risks to occupational health associated with climate change include increased risk of malaria and dengue fever in field workers, and injuries and mortality risks from extreme weather events and flooding

Migration and displacement: The social, economic, and environmental factors underlying migration decisions are complex and varied, making it difficult to observe or estimate the magnitude of climate change effects.

Populations living in the arctic, tropical regions, and on small-island developing states face the

greatest threat of displacement. In the 2oC of global warming scenario, these populations may be required to move distances greater than 1000 km with evacuation from these areas to tropical margins and the subtropics increasing population density in these destinations by 300%

Conflict: Climate change could be one of the many drivers of conflict in various regions. For example, drought has been shown to significantly increase the likelihood of sustained conflict for nations or groups dependent on agricultural livelihoods

Regional impacts

CLIMATE CHANGE

The negative impacts of climate change on the environment and human beings by the end of the 21st century, unless we do all we can to reduce greenhouse gas emissions.

2.0°C
Temperature rise by 2100

1.0m
Sea level rise by 2100

2 billion people
Additional people who will need to be fed by 2100

1/3 of the world population
People who will be living in water stress by 2100

1.8 billion people
People who will be living in water stress by 2100

2°C
Temperature rise by 2100

THE ARCTIC
Rapid warming and melting of ice sheets and glaciers. Permafrost is melting, leading to the release of greenhouse gases. Arctic wildlife is losing habitat and struggling to survive.

NORTH AMERICA
Negative impacts on human beings: More severe weather, including droughts, floods, and wildfires. Negative impacts on the environment: Loss of biodiversity, including the extinction of some species.

SOUTH AMERICA
Negative impacts on human beings: More severe weather, including droughts, floods, and wildfires. Negative impacts on the environment: Loss of biodiversity, including the extinction of some species.

EUROPE
Negative impacts on human beings: More severe weather, including droughts, floods, and wildfires. Negative impacts on the environment: Loss of biodiversity, including the extinction of some species.

AFRICA
Negative impacts on human beings: More severe weather, including droughts, floods, and wildfires. Negative impacts on the environment: Loss of biodiversity, including the extinction of some species.

ASIA
Negative impacts on human beings: More severe weather, including droughts, floods, and wildfires. Negative impacts on the environment: Loss of biodiversity, including the extinction of some species.

AUSTRALIA
Negative impacts on human beings: More severe weather, including droughts, floods, and wildfires. Negative impacts on the environment: Loss of biodiversity, including the extinction of some species.

ANTARCTICA
Rapid warming and melting of ice sheets and glaciers. Permafrost is melting, leading to the release of greenhouse gases. Antarctic wildlife is losing habitat and struggling to survive.

<https://climate.bas.com/resources/climate-change-map/>

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Classification of climate-related hazards to health care facilities and overall health

Climate hazard groups:

A. Hydro-meteorological

	HAZARD TYPE	EXAMPLES OF EXPOSURE PATHWAYS
Hydrological	Flood • Riverine • Coastal • Flash • Mudslides • Erosion	<ul style="list-style-type: none"> • Water, soil, food contamination • Lack of power • Increased vector habitat • Flooded health care facilities • Flooded sewage and waste areas • Impaired access to health care facilities • Impacts on the supply chain • Impaired mobility and transportation
	Storm • Tropical cyclones • Local storms • Winds • Dust storms	<ul style="list-style-type: none"> • Lack of power • Damaged health care facilities • Impaired access to health care facilities • Water, soil contamination • Particulate matter (air pollution) • Disruption of food productivity
Meteorological	Extreme temperature • Heatwaves • Cold waves	<ul style="list-style-type: none"> • Power outages • Water, food contamination • Air pollution (ozone formation) • Impaired access to food and water • Frozen water pipes* • Loss of water pressure* • Internal flooding of health care facilities* • Impaired mobility and transportation* <p>(*cold wave specific)</p>

WHO, Checklists to assess vulnerabilities in health care facilities in the context of climate change, ISBN 978-92-4-002290-4 (electronic version) – pp. 12-13

Classification of climate-related hazards to health care facilities and overall health

Climate hazard groups:

A. Hydro-meteorological

	HAZARD TYPE	EXAMPLES OF EXPOSURE PATHWAYS
Climatological	Drought <ul style="list-style-type: none"> • Meteorological • Hydrological • Agricultural 	<ul style="list-style-type: none"> • Reduced water access • Reduced hygiene • Lack of power • Water contamination • Reduced ability to deliver services • Increased water salinity • Dust and air pollution • Reduced land productivity causing food insecurity
	Wildfire	<ul style="list-style-type: none"> • Power outages • Direct threats to health infrastructure • Impacts on the supply chain • Impaired access to health care facilities • Air pollution

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Classification of climate-related hazards to health care facilities and overall health

Climate hazard groups:

B. Environmental

HAZARD TYPE	EXAMPLES OF EXPOSURE PATHWAYS
Sea-level rise <ul style="list-style-type: none"> • Recurrent or permanent coastal floods and erosion 	<ul style="list-style-type: none"> • Increased salinity intrusion (water, soil) • Freshwater contamination • Food contamination • Flooded health care facilities • Flooded sewage and waste areas • Impaired access to health care facilities
Direct hazard from increased temperatures <ul style="list-style-type: none"> • Accelerated growth, transmission, virulence of certain pathogens leading to increased biological hazards • Ozone formation 	<ul style="list-style-type: none"> • Increased biological hazards • Change in climate-sensitive diseases (increase in health care facility admissions) • Water and food contamination • Air pollution (ozone formation) • Impacts on biodiversity (control of new pathogens) • Threats to building infrastructure from melting permafrost

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Classification of climate-related hazards to health care facilities and overall health

Climate hazard groups:

C. Biological (climate-sensitive diseases)

HAZARD TYPE	EXAMPLES OF EXPOSURE PATHWAYS
Airborne diseases	<ul style="list-style-type: none"> • Respiratory infections • Meningococcal meningitis • Influenza
Waterborne diseases	<ul style="list-style-type: none"> • Diarrhoeal diseases • Cholera • Typhoid fever
Foodborne diseases	<ul style="list-style-type: none"> • Hepatitis A • Foodborne microbial hazards
Zoonotic diseases	<ul style="list-style-type: none"> • Leptospirosis • Hantavirus disease
Vectorborne diseases	<ul style="list-style-type: none"> • Dengue • Malaria • Chikungunya • Zika • Rift Valley fever • West Nile virus • Lyme disease

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Classification of climate-related hazards to health care facilities and overall health

Climate hazard groups:

D. Climate-sensitive health outcomes

Noncommunicable diseases and injuries

- Chronic respiratory diseases
- Cardiovascular diseases
- Unintentional injuries
- Mental health outcomes
- Malnutrition
- Kidney diseases

E. Technological (mediated by climate hazards)

Industrial hazards (as a result of a climate hazard such as a storm, flood, or wildfire)

- Chemical spill
- Structural collapse
- Occupational hazards (health workforce)
- Environmental pollution (air, water, soil)
- Food contamination
- Infrastructure disruption causing: power outages; contamination of water supply, solid waste, wastewater, food and water; communication system failure; medical equipment, products and services, supply system failure; build up of hazardous waste

F. Societal (mediated by climate hazards)

Displaced populations

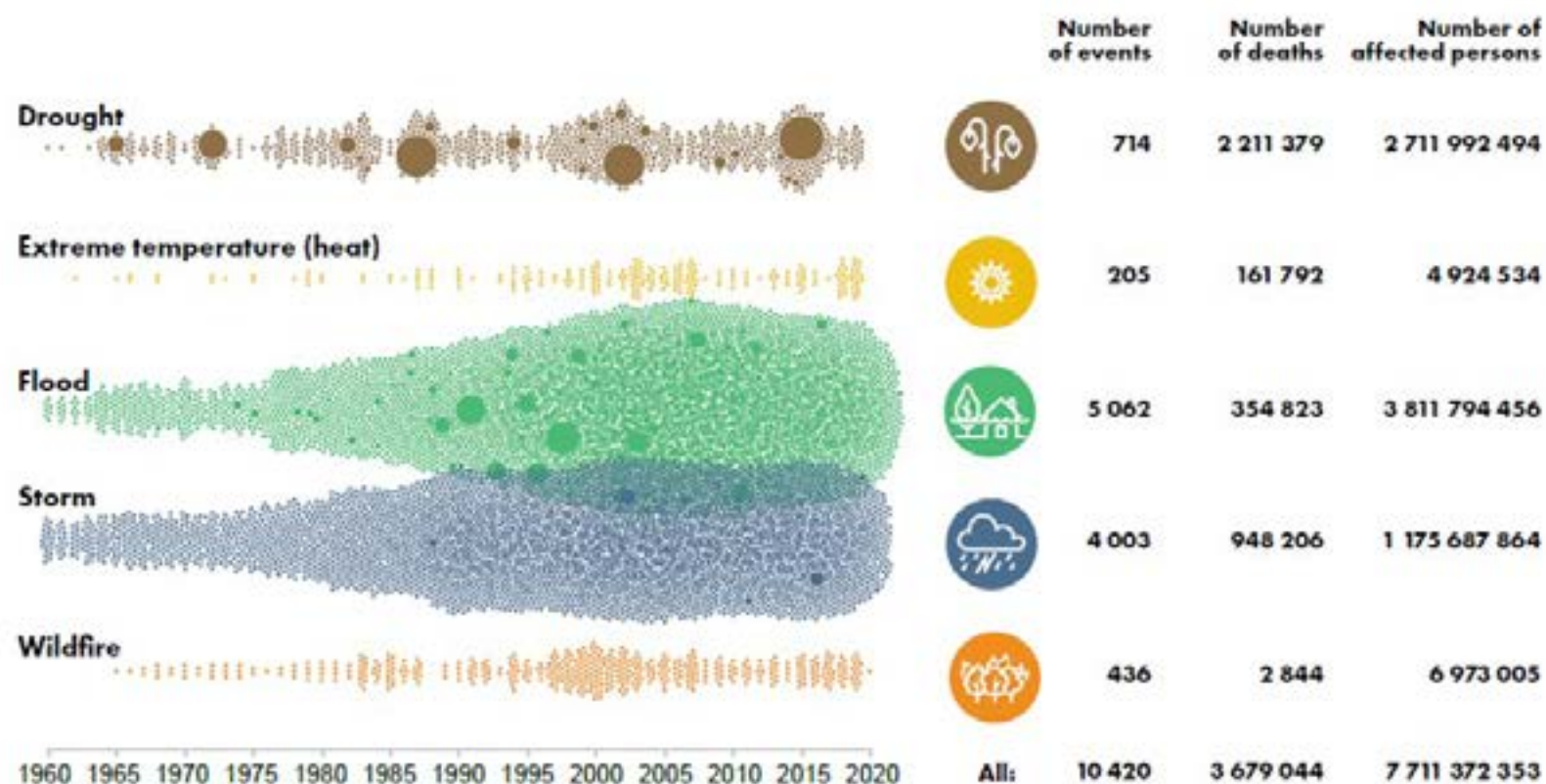
Famine

- Water and food scarcity
- Mental health problems
- Protein-energy malnutrition
- Conflict and violence

WHO, Checklists to assess vulnerabilities in health care facilities in the context of climate change, ISBN 978-92-4-002290-4 (electronic version) – pp. 12-13

Number of events, deaths and affected persons since 1960, for drought, extreme temperature (heat), flood, storm and wildfire

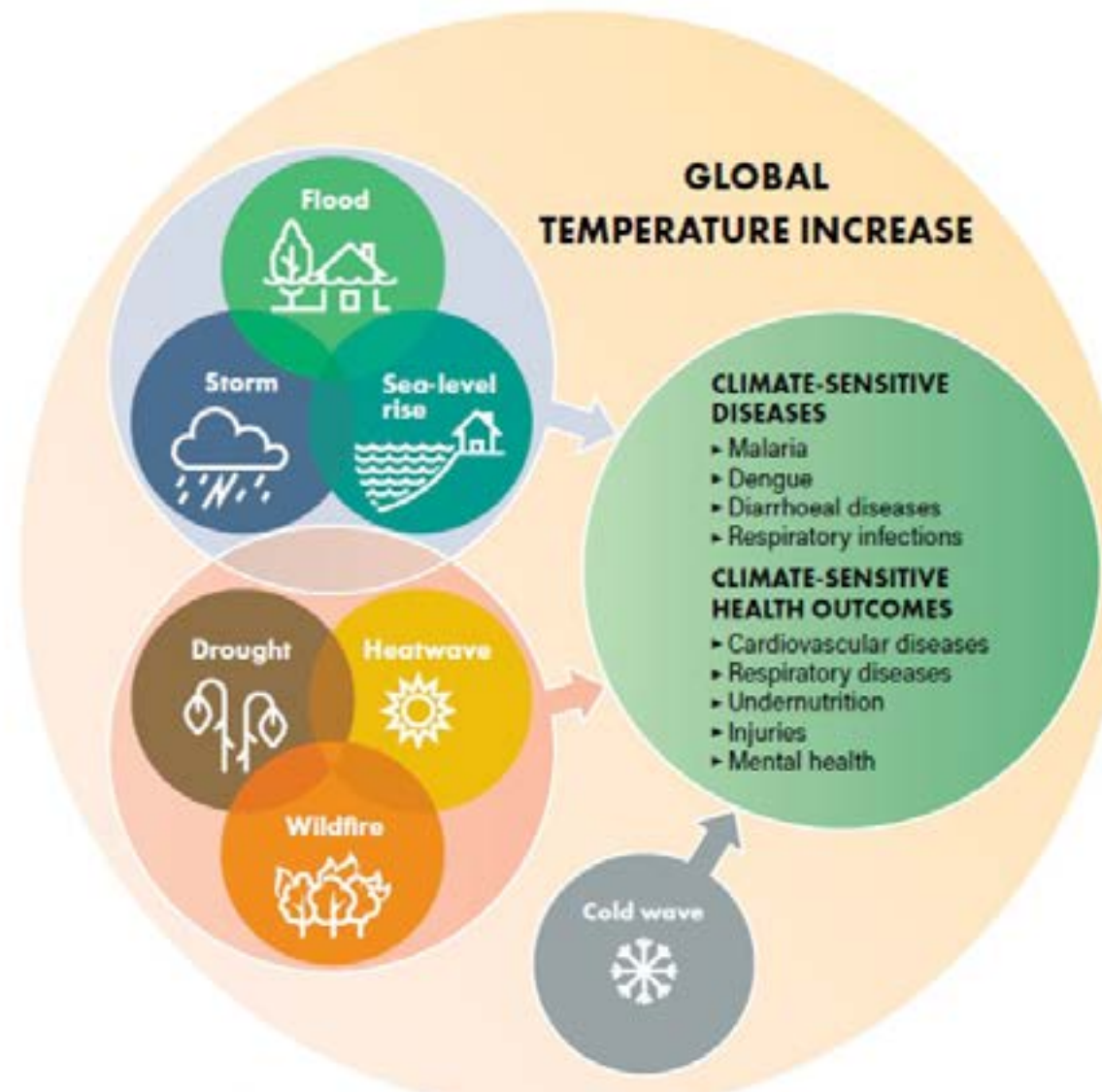
6.



Note: Each dot represents an event; circle size represents the number of affected persons.


Sources: (24); graphs produced with RAW Graphics (25).

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WHO. Checklists to assess vulnerabilities in health care facilities in the context of climate change, ISBN 978-92-4-002290-4 (electronic version) – p. 22


Climate-sensitive diseases and climate-sensitive health outcomes

CLIMATE HAZARD	CLIMATE-SENSITIVE DISEASES (INFECTIOUS DISEASES)	CLIMATE-SENSITIVE HEALTH OUTCOMES (NONCOMMUNICABLE DISEASES AND UNINTENTIONAL INJURIES)
INCREASED TEMPERATURE 	Waterborne diseases (diarrhoeal diseases, <i>Naegleria fowleri</i> infection, campylobacter infection, cholera, harmful algal bloom toxins); vectorborne diseases (dengue, malaria, Lyme disease, West Nile virus, Rift Valley fever, tickborne encephalitis); zoonotic diseases (rodentborne diseases, hantavirus diseases, leptospirosis); foodborne diseases (salmonellosis, mycotoxin effects); airborne diseases (influenza and other respiratory infections)	Cardiovascular diseases; chronic respiratory diseases (asthma, chronic obstructive pulmonary disease (COPD), respiratory allergies); protein-energy malnutrition (adverse nutritional effects causing childhood stunting)


WHO. Checklists to assess vulnerabilities in health care facilities in the context of climate change, ISBN 978-92-4-002290-4 (electronic version) – pp. 17-19

CLIMATE HAZARD	CLIMATE-SENSITIVE DISEASES (INFECTIOUS DISEASES)	CLIMATE-SENSITIVE HEALTH OUTCOMES (NONCOMMUNICABLE DISEASES AND UNINTENTIONAL INJURIES)
FLOOD 	Water- and food-borne diseases (diarrhoea from bacterial, viral and parasitic diseases, hepatitis A, typhoid fever, gastroenteritis, salmonellosis, <i>Escherichia coli</i> infection, cholera, cryptosporidium, campylobacteriosis, intestinal nematode infections); vectorborne diseases (dengue, Zika virus disease, malaria, chikungunya, West Nile virus fever); zoonotic diseases (rabies, rodentborne diseases, hantavirus diseases, leptospirosis); acute respiratory infections (influenza, pneumonia); eye and skin infections; tetanus; legionellosis	Deaths; drowning; physical traumas; hypothermia; animal bites; chemical poisoning and intoxication; electrical shock; mental health effects (acute traumatic stress, anxiety and depression, insomnia); cardiovascular diseases (stroke, diabetes, heart attack); chronic respiratory diseases (asthma, COPD, respiratory allergies); venomous animal bites (snakes, scorpions); eye, nose and skin irritation; protein-energy malnutrition; renal failure (due to lack of access to health care, dialysis)


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CLIMATE HAZARD	CLIMATE-SENSITIVE DISEASES (INFECTIOUS DISEASES)	CLIMATE-SENSITIVE HEALTH OUTCOMES (NONCOMMUNICABLE DISEASES AND UNINTENTIONAL INJURIES)
STORM 	Diarrhoeal diseases; cholera; hepatitis A; vectorborne diseases; zoonotic diseases; intestinal nematode infections; tetanus; respiratory infections; polymicrobial wound infections (by <i>Escherichia coli</i> , <i>Klebsiella</i> , <i>Serratia</i> , <i>Proteus</i> and <i>Pseudomonas</i>); mucormycosis	Deaths; drowning; physical traumas; wounds; hypothermia; animal bites; chemical poisoning and intoxication; electrical shock; mental health effects (acute traumatic stress, anxiety and depression, insomnia); cardiovascular diseases; chronic respiratory diseases (asthma, COPD, respiratory allergies); protein-energy malnutrition; renal failure (due to lack of access to health care, dialysis)


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CLIMATE HAZARD	CLIMATE-SENSITIVE DISEASES (INFECTIOUS DISEASES)	CLIMATE-SENSITIVE HEALTH OUTCOMES (NONCOMMUNICABLE DISEASES AND UNINTENTIONAL INJURIES)
SEA-LEVEL RISE 	Diarrhoeal diseases; cholera; hepatitis A; vectorborne diseases; zoonotic diseases; respiratory infections	Deaths; drowning, electrical shock; mental health (acute traumatic stress, anxiety and depression); cardiovascular diseases (hypertension); chronic respiratory diseases (asthma, COPD, respiratory allergies); protein-energy malnutrition; kidney disease


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CLIMATE HAZARD	CLIMATE-SENSITIVE DISEASES (INFECTIOUS DISEASES)	CLIMATE-SENSITIVE HEALTH OUTCOMES (NONCOMMUNICABLE DISEASES AND UNINTENTIONAL INJURIES)
DROUGHT 	Diarrhoeal diseases; cholera; hepatitis A; vectorborne diseases (dengue, malaria, Zika virus disease, chikungunya, Lyme disease, West Nile virus fever, Valley fever); zoonotic diseases; intestinal nematode infections; respiratory infections; eye and skin infections (scabies, trachoma, conjunctivitis); meningococcal meningitis	Cardiovascular diseases; chronic respiratory diseases (asthma, COPD, respiratory allergies); kidney diseases; cancers (skin, bladder, lung); protein-energy malnutrition; mental health effects (stress, anxiety and depression); eyes, nose and skin irritation; musculoskeletal problems


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HEATWAVE 	Respiratory infections; water- and food-borne diseases (campylobacteriosis, salmonellosis, diarrhoeal diseases, cholera, cryptosporidiosis); harmful algal bloom toxins	Death; cardiovascular diseases (stroke, heart diseases, diabetes, thrombogenesis); heat stress; heat exhaustion; heat syncope; heat oedema; heat rash; dehydration-induced heat cramps; chronic respiratory diseases (asthma, COPD, respiratory allergies); protein-energy malnutrition; kidney disorder; aggravated chronic pulmonary conditions; eyes and skin irritation; mental illness; metal and chemical toxicity

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WILDFIRE 	Increased susceptibility to respiratory infections	Death; burns; injuries; mental health effects (acute traumatic stress, anxiety and depression, insomnia); chronic respiratory diseases (asthma, COPD, respiratory allergies); cardiovascular diseases (heart stroke, diabetes); dehydration-induced heat cramps; smoke intoxication (from particulate matter and other air pollutants); wheezing and shortness of breath; adverse pregnancy outcomes (e.g. low birth weight and preterm birth); carbon monoxide poisoning; eyes, nose and skin irritation (corneal abrasion)

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COLD WAVE 	Respiratory infections (such as influenza)	Deaths; cardiac workload leading to cardiovascular stress (heart diseases); exposure to extreme cold which causes veins and arteries to narrow and blood to become more viscous increasing cardiac workload; hypothermia leading to cardiac workload; aggravation of pre-existing chronic diseases such as diabetes, respiratory diseases (asthma, chronic bronchitis and emphysema) and cardiovascular conditions (heart diseases, stroke); frostbite (freezing of skin exposed to the cold)

WHO. Checklists to assess vulnerabilities in health care facilities in the context of climate change, ISBN 978-92-4-002290-4 (electronic version) – pp. 17-19

Take-home messages

- To make ourselves aware that climate change is now a major health risk and an excess of deaths
- To pay more attention to the most vulnerable groups and the effects in our own environment
- To be aware that we are in the middle of the climate crisis and that the responsibility is shared, while avoiding the unwanted effects of global warming is at the same time the challenge of today to make reasonable changes in our own way of life
- These trainings can provide up-to-date knowledge about the effects of climate change on human health and can help to cope with the new challenges caused by climate change.

Test your knowledge

- What should we do to reduce the emissions of greenhouse gases?
- Please enumerate the vulnerable population, the most sensitive groups.
- Please give examples for direct impacts of climate change on human health.
- Please give examples for indirect impacts of climate change on human health.
- Which is the influence of global warming on migration?
- Which continent is most affected on climate change?
- Which are the climate-related biological hazard types to health care facilities and overall health?
- Which are the most important climate-sensitive health outcomes?

Main references

- Checklists to assess vulnerabilities in health care facilities in the context of climate change. Geneva: World Health Organization, 2021, ISBN 978-92-4-002290-4
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- <https://chasecanada.org/wp-content/uploads/2021/01/Climate-Change-Toolkit-for-Health-Professionals-Full-Toolkit.pdf>, accessed 20 June 2023
- <https://www.ipcc.ch/site/assets/uploads/2020/11/The-Regional-Impact.pdf>, accessed 20 June 2023

Thank you for your attention!

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CLIMATEMED – Knowledge about climate change's health impacts starts here



Thermoregulation, effects of heat and heat stroke

Learning outcomes

Upon successful completion the students will be able to

- understand the thermoregulatory and haemodynamic responses to excessive heat exposure;
- understand the mechanisms, clinical manifestations, diagnosis and treatment of heat illnesses;
- recognize early signs of heat stroke, which is a medical emergency;
- initiate proper cooling and resuscitative measures

Extreme Heat

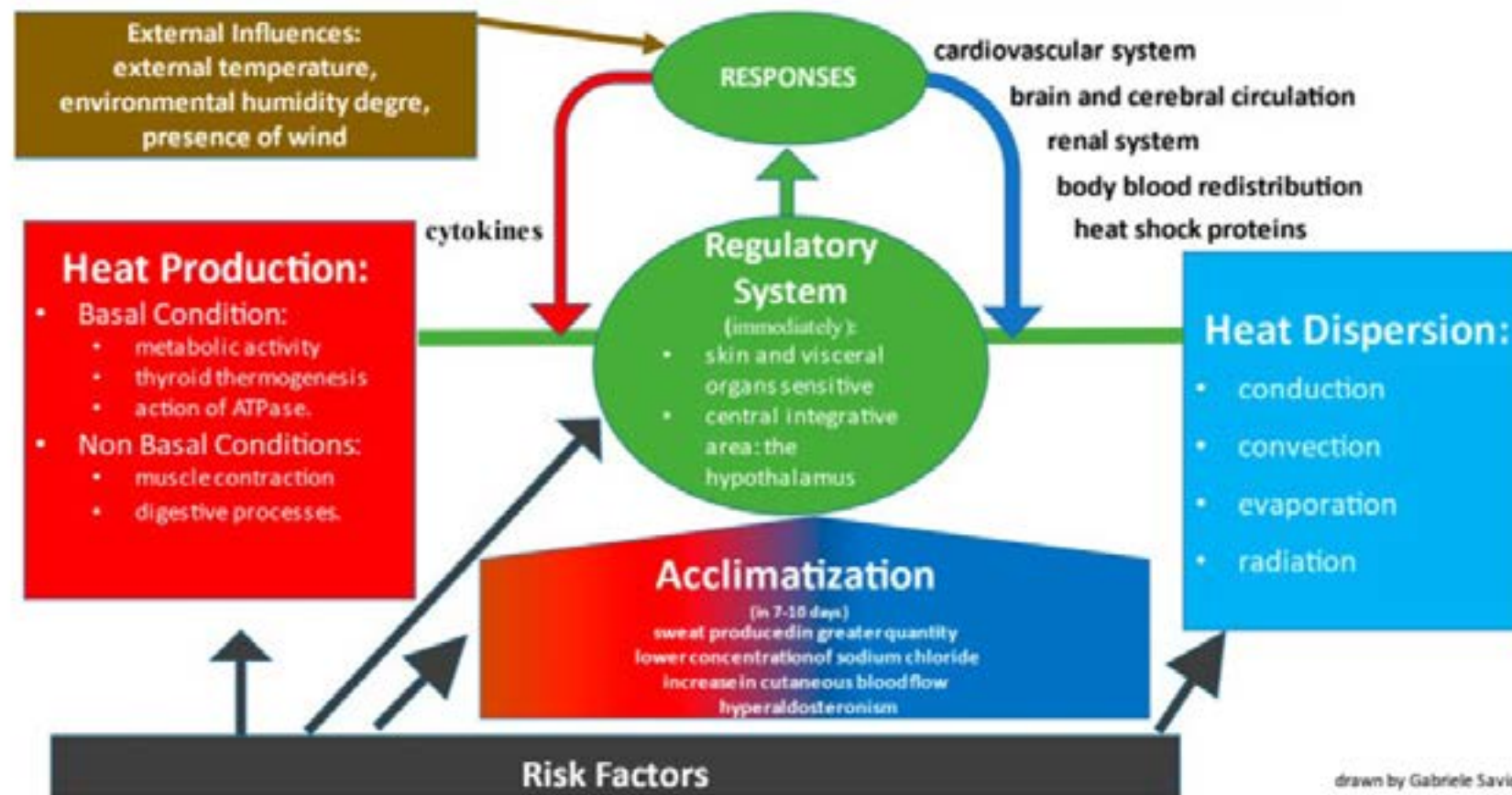
Key points

- Climate change poses unique risks to a **rapidly growing demographic of elderly patients**.
- **Clinicians, hospitals, policy makers and financial planners must prepare** for these current and future needs.
- **Integrating weather modeling and public health intervention** to address vulnerable populations may ease the burden of heat stress on individuals and the health care system.

Key points

- **Resources are needed** to address environmental **disparities** and provide protective measures against heat related illness in the inner city.
- Rapid warming as well as rapid development are occurring in the developing world. To keep populations safe-guarded against the negative effects of extreme heat, **innovative cooling solutions are necessary**.
- **Elderly populations** are particularly **vulnerable** to heat stress, a factor that should be incorporated into routine care.

THERMAL HOMEOSTASIS, HEAT STRESS AND RESPONSE



drawn by Gabriele Savioli

When the body is under heat stress, thermal homeostasis is maintained through the regulated balance (immediately for the regulatory system and after 7–10 days through the acclimatization process) among the factors that produce heat (red square) and heat dissipation (blue square). However, modifiable and non-modifiable risk factors can compromise both the regulation and acclimatization systems and the factors capable of producing or dispersing heat.

Source: doi: [10.3390/biomedicines10102542](https://doi.org/10.3390/biomedicines10102542)

At-risk groups

EVERYBODY can be affected by high temperatures, but there are certain factors that increase an individual's risk during a heatwave. These include:

- **older age:** especially those over 75 years old, or those living on their own and who are socially isolated, or those living in a care home
- **chronic and severe illness:** including heart or lung conditions, diabetes, renal insufficiency, Parkinson's disease or severe mental illness
- **inability to adapt behaviour to keep cool:** babies and the very young, having a disability, being bed bound, consuming too much alcohol, having Alzheimer's disease
- **environmental factors and overexposure:** living in a top floor flat, being homeless, activities or jobs that are in hot places or outdoors and include high levels of physical exertion

Source: The health impacts of hot weather and the Heatwave Plan for England

https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_TechnicalSummary.pdf

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Health professionals should understand why risk increases

- Groups at increased risk:
 - Elderly
 - sweat less, less thirst drive
 - Non-ambulatory
 - May not seek cooler locations or hydrate
 - Cardiopulmonary and renal conditions
 - Circulatory burden and dehydration
 - Mental health medications
 - Thermoregulation
 - Children (0-4) and older kids – thermoregulatory issues and activities
 - Sports Enthusiasts – may overdo
 - Labourers – may be placed at greater risk
 - Homeless – may not recognize the danger or have resources to cope

Thermoregulation

- Thermoregulation is the regulation of body temperature
- Ways of heat exchange – Definitions
- Physiology of Temperature Control
- Thermoregulation in infants
- Aging and thermoregulation

What is thermoregulation?

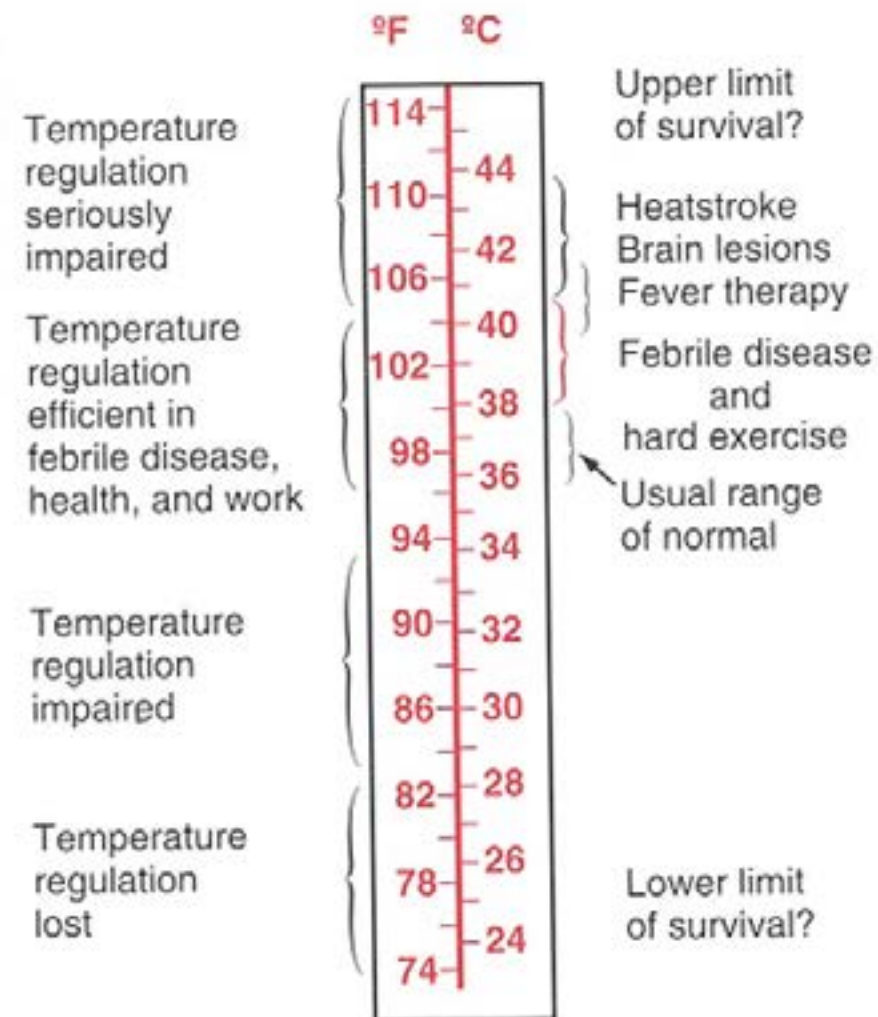
- Complex interplay between central and peripheral processes
- Normothermia is the normal core body temperature (36.8 - 37.2 °C)
- When humans are exposed to heat stress (i.e. elevated environmental temperatures,

physical activity, or a combination of both), the thermoregulatory system engages a number of physiological mechanisms to maintain heat balance.

- The internal heat produced by cellular respiration (metabolic heat production) is balanced out by the rate of heat that is lost

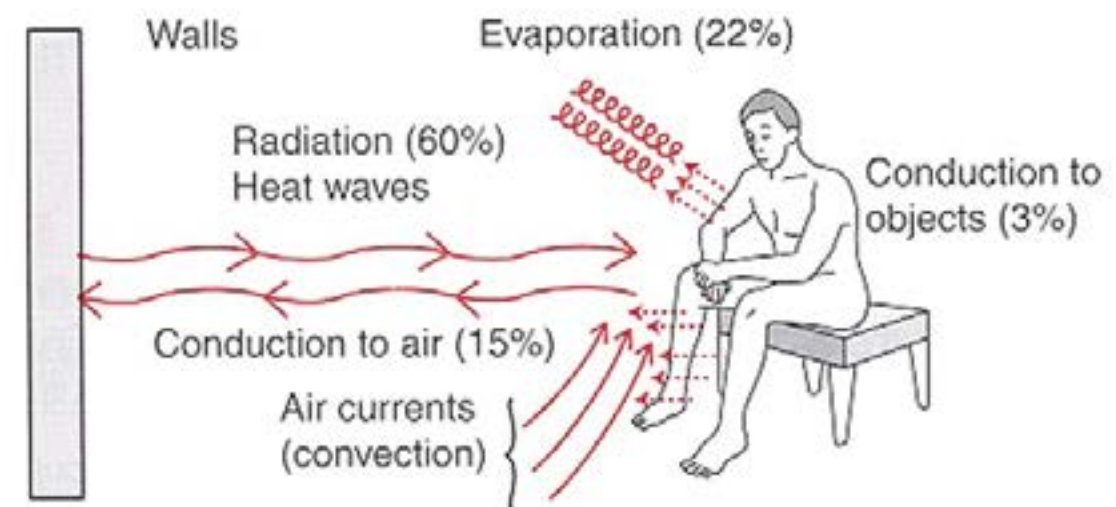
from the skin surface to the surrounding environment through a combination of dry (conduction, convection, and radiation) and evaporative heat exchange.

Body temperature and health effects



Thermoregulation - ways of heat exchange - Definitions

- Radiation
 - Loss of heat by infrared heat rays (5-20 μ m or 10-20X wavelength of visible light)
- Conduction
 - Loss of heat from the body to a solid object
- Evaporation
 - Loss of heat from the body through water vapor to the surrounding atmosphere
- Convection
 - Effects of changes in the external environment (e.g., wind and water)



Source: Pediatric Thermoregulation - Society for Pediatric Anesthesia pedsanesthesia.org

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What is thermoregulation?

Thermoregulation is the regulation of body temperature

- Complex **interplay** between central and peripheral processes
- **Normothermia** is the normal core body temperature (36.8 - 37.2 °C)
- When humans are exposed to heat stress (i.e. elevated environmental temperatures, physical activity, or a combination of both), the thermoregulatory system **engages a number of physiological mechanisms to maintain heat balance.**
- The **internal heat produced by cellular respiration** (metabolic heat production) is balanced out by the **rate of heat that is lost from the skin** surface to the surrounding environment through a combination of dry (conduction, convection, and radiation) and evaporative heat exchange.

Source: Pediatric Thermoregulation - Society for Pediatric Anesthesia pedsanesthesia.org

Physiology of Temperature Control - 1

Inputs

Thermal inputs travel along A delta (cold) and C (warm) fibers via the spinothalamic tract in the anterior spinal cord.

Input comes from the skin, deeper tissues, hypothalamus, and other parts of the brain and spinal

Source: Pediatric
Thermoregulation -
Society for Pediatric
Anesthesia
pedsanesthesia.org

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Physiology of Temperature Control - 2

Central regulation

Central regulation begins with pre-processing in the spinal cord and brainstem. Inputs are modulated by a number of neurotransmitters.

The hypothalamus is the integrator of temperature information. It compares inputs with threshold temperatures to determine each thermoregulatory response.

The dorsomedial nucleus, periaqueductal gray matter of the midbrain, and the nucleus raphe pallidus in the medulla also play an important role.

*Source: Pediatric
Thermoregulation -
Society for Pediatric
Anesthesia
pedsanesthesia.org*

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Physiology of Temperature Control - 3

Responses

Efferent responses are both behavioral and autonomic.

Behavioral responses are primarily determined by skin temperature input and include things like going inside when it's cold outside, putting on a sweater, and moving around or doing in the opposite way when it is hot.

Autonomic responses are primarily determined by core temperature input and include skin vasomotor activity, vasoconstriction or vasodilation and sweating.

Source: Pediatric
Thermoregulation -
Society for Pediatric
Anesthesia
pedsanesthesia.org

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How does thermoregulation in infants differ?

Body surface area-to-volume ratio

- Adults: 0.4
- Normal infants: 1

Heat loss and gain are much more rapid in infants

→ Excessive heat accumulation or liberation compromises

→ the physiological function of cellular and organ systems, which can lead to impaired human performance.

→ A well-developed control system is therefore required to regulate heat exchange within the body and between the skin and the environment.

Source: Pediatric Thermoregulation – Society for Pediatric Anesthesia pedanesthesia.org

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Heat exchange

- The two avenues of heat exchange inside the body are
- 'intercellular conductive heat transfer' and
- 'vascular convective heat transfer'.
- Heat conductance through tissues in the human body is a slow process and, in limbs, is primarily dependent upon the temperature gradient between muscle and skin and the thermal conductivity of muscle.
- The haemodynamic responses to environmental stress are determined by the magnitude of the environmental (heat or cold) load and the duration.

Heat exchange

- Heat transfer via the flowing blood (i.e. vascular convective heat transfer) is the most important heat-exchange pathway inside the body.
- Heat storage in body tissues depends upon the interplay among heat production, heat dissipation and, to a lesser extent,
 - energy exchanged during mechanical work.

Aging and thermoregulatory control

- Older individuals have **impaired thermoregulatory control** and their risk of heat-related illness is elevated, particularly when performing physical activity in the heat.
- Increases in metabolic and muscular activity increases heat production.
- The change in core body temperature secondary to the additional heat energy stored inside the body provides thermal afferent impulses to the central nervous system, which subsequently sends efferent signals to appropriate effector organs to initiate sustained increases in sweating and skin blood flow ensuring that core body temperature is maintained within safe limits.

Source: Balmain BN, et al.: Aging and Thermoregulatory Control: The Clinical Implications of Exercising under Heat Stress in Older Individuals. doi: 10.1155/2018/8306154.

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Age-related changes in sweating

- Older individuals demonstrate a delayed core temperature onset threshold for sweating and a reduction in evaporative heat loss (due to a lower overall sweat rate) compared to their younger healthy counterparts.
- These age-related decrements in sweating do not appear to be due to a reduction in the number of activated sweat glands, but rather to a reduction in the amount of sweat produced per gland.
- Sweat gland function may decline in a peripheral-to central direction as skin ages.

- The attenuated evaporative heat loss capacity found in older individuals results in greater heat energy stored inside the body which can cause core body temperature to rise to potentially dangerous levels.

Age-related changes in skin blood flow (SkBF)

- Cutaneous vasomotor tone provides an effective means of managing a thermal load by redistributing cardiac output to modulate SkBF.
- The thermoregulatory-induced redistribution of blood flow to the skin is seen as a fundamental thermoregulatory response.

→ Older individuals exhibit

- attenuated increases in SkBF for a given change in core temperature,
- lower time-dependant changes in SkBF compared to younger individuals.

Age-related changes in skin blood flow (SkBF)

- Thermoregulatory-induced rises in SkBF are primarily mediated by a sympathetic cholinergic active vasodilator system. Active cutaneous vasodilation is mediated through the release of acetylcholine and unknown cotransmitters, which facilitate cutaneous vasodilation through NO-dependent mechanisms.
- Older individuals exhibit an impaired vasodilatory response to hyperthermia and can be attributed to decreased sensitivity of the active vasodilator system. This decreased sensitivity results in reduced cotransmitter signalling and, thus, attenuated NO-dependent cutaneous vasodilation.

- Hence, compared to younger individuals, older individuals predominately rely on compromised nitric oxide- (NO-) dependant cutaneous vasodilation to increase SkBF in response to environmental heat exposure and/or physical activity.



Aging and thermoregulatory control

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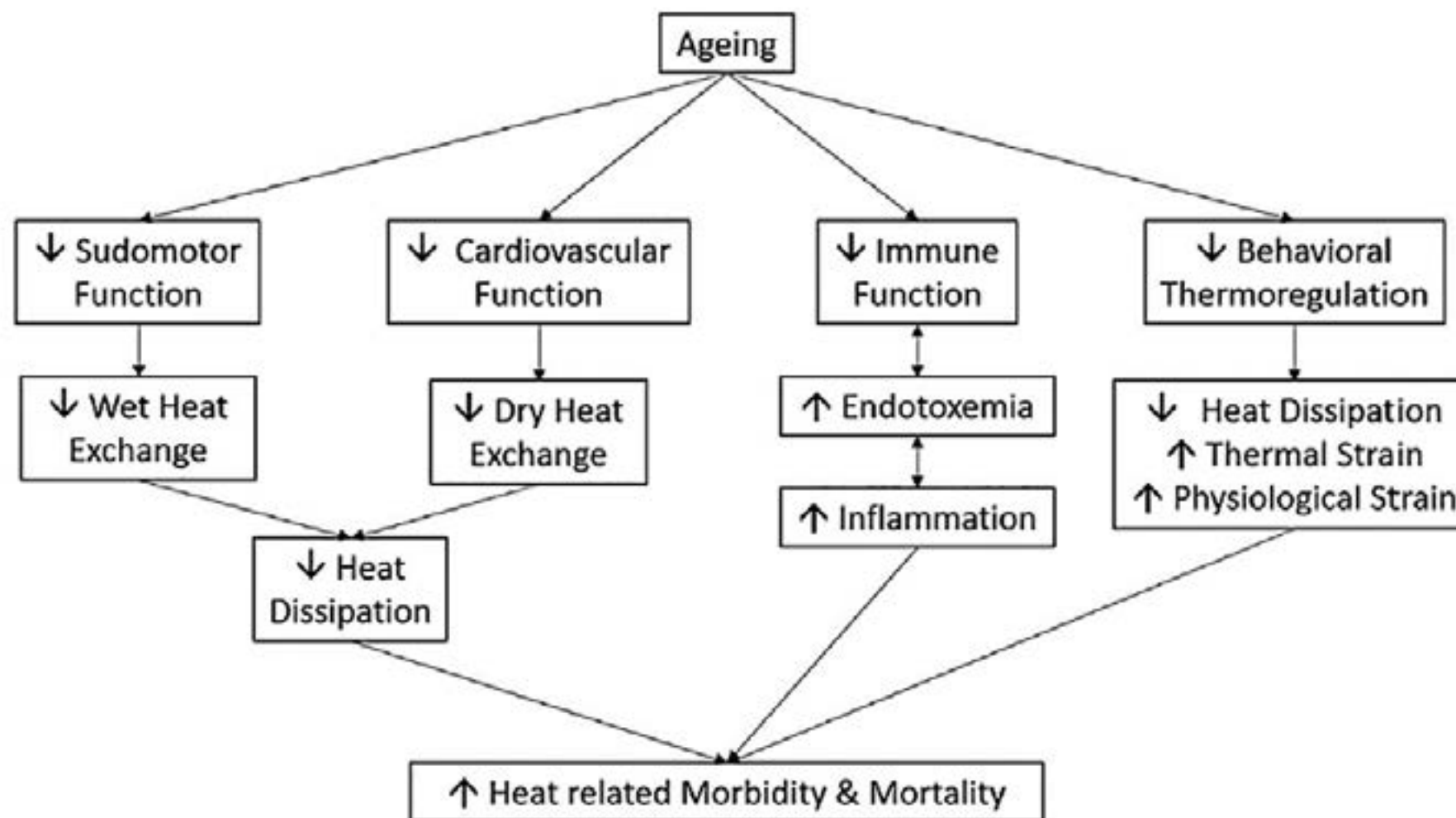
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Other special differences

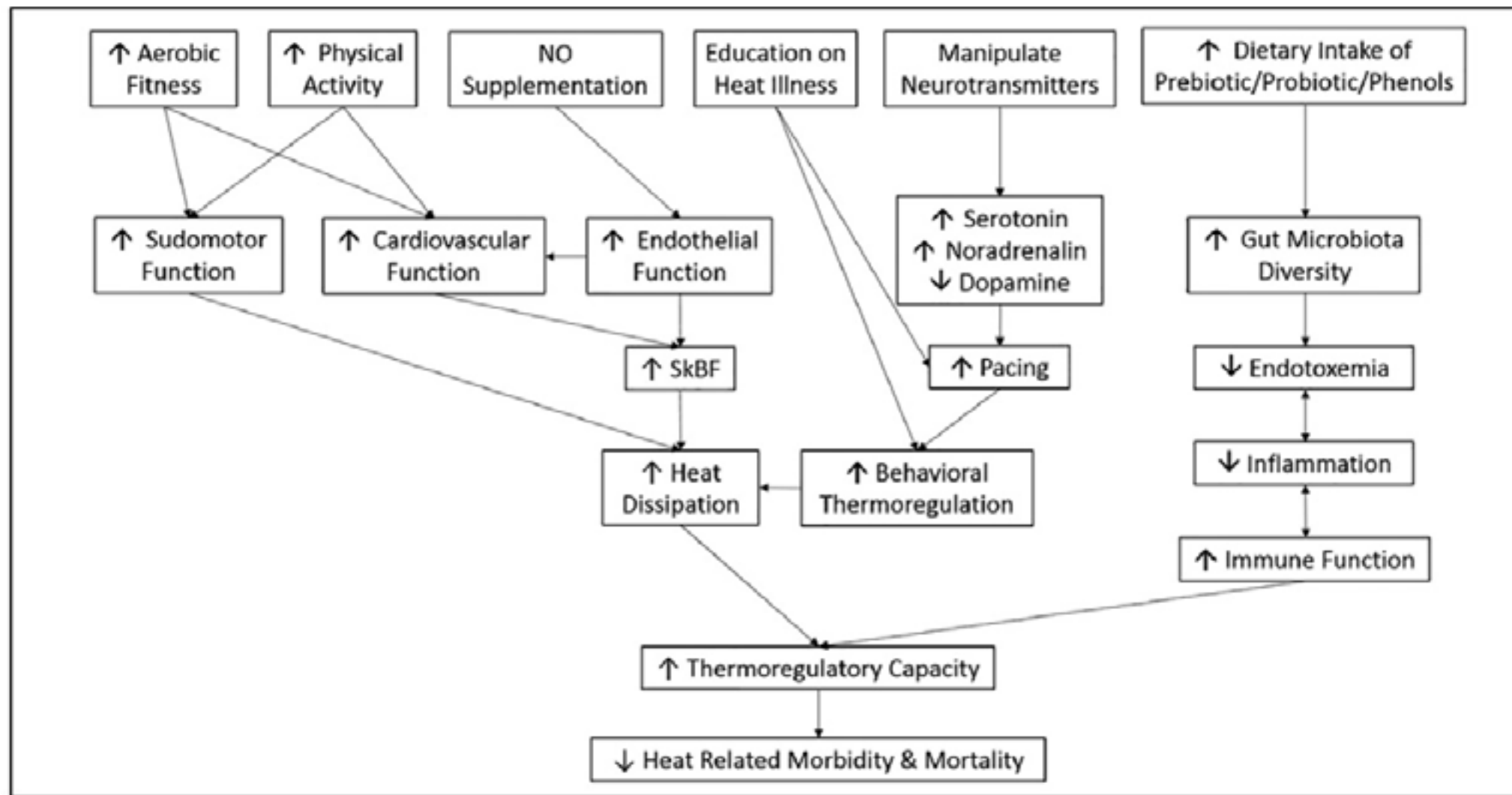
- Older individuals exhibit a lower cardiac output during passive heat stress compared to younger individuals.
- Less cardiac output and blood flow redistribution during heat stress may be due to age-related changes in fluid status.
- Older individuals exhibit decrements in thirst sensation, and renal sodium- and water-conserving capabilities decline with advancing age.
- As such, these findings suggest that the capacity to accommodate large increases in intravascular blood volume and that the amount of blood available to circulate through the cutaneous vasculature are

limited in older individuals compared to their younger counterparts.



Factors contributing to increased risk of heat illness and death in aging

Source: Balmain BN, et al.: Aging and Thermoregulatory Control: The Clinical Implications of Exercising under Heat Stress in Older Individuals. doi: 10.1155/2018/8306154.



Proposed interventional strategies and mechanisms to improve thermoregulation in the elderly.

Source: Millyard A, et al. *Impairments to Thermoregulation in the Elderly During Heat Exposure Events..* doi: 10.1177/2333721420932432.

Take home message - thermoregulation

How to prevent heat illnesses

Risk groups	Mechanism	Prevention
Infants	Thermoregulation immature, smaller body mass and blood volume, high dependency level, Dehydration risk in case of diarrhoea	Keep the inner environment cool. Check room and body temperature. Supply fluid and electrolite.
Females and elderly or very elderly	Changes in thermoregulation, renal function and health status, reduced water intake and Reduced physical ability	Keep the inner environment cool. Check room and body temperature. Supply fluid and electrolite. Restrict physical activity. Follow medication, prevent side effects. Keep medicines cool.

Heat related illnesses

- Diagnosis and treatment of heatstroke
- Comparison of high body temperature and acute infection
- Comparison of heat exhaustion and heat stroke
- Mild and moderate heat illnesses and their management
- Management of life-threatening heatstroke

Heat related illnesses

Heat syncope – dizziness and fainting, due to dehydration, vasodilation, cardiovascular disease and certain medications

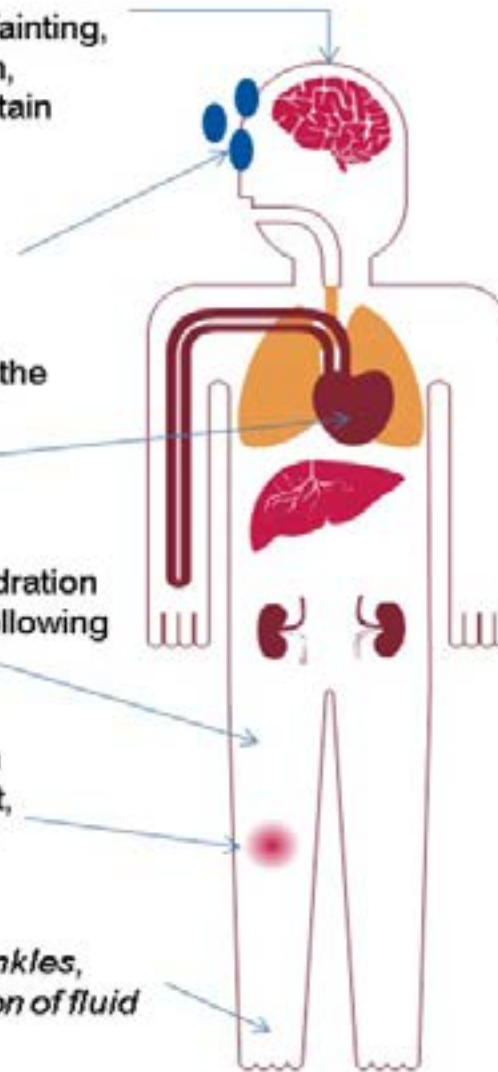
Excessive sweating can deplete fluid and salts

When blood temperature rises, the body stimulates sweat glands, dilates blood vessels and increases the heart rate

Heat cramps – caused by dehydration and loss of electrolytes, often following exercise

Increased blood flow to the skin cools the body by radiating heat, leading to heat rash (small, red itchy papules)

Heat oedema – mainly in the ankles, due to vasodilation and retention of fluid



Health effects of heat

The main causes of illness and death during a heatwave are respiratory and cardiovascular diseases. Additionally, there are specific heat-related illnesses including:

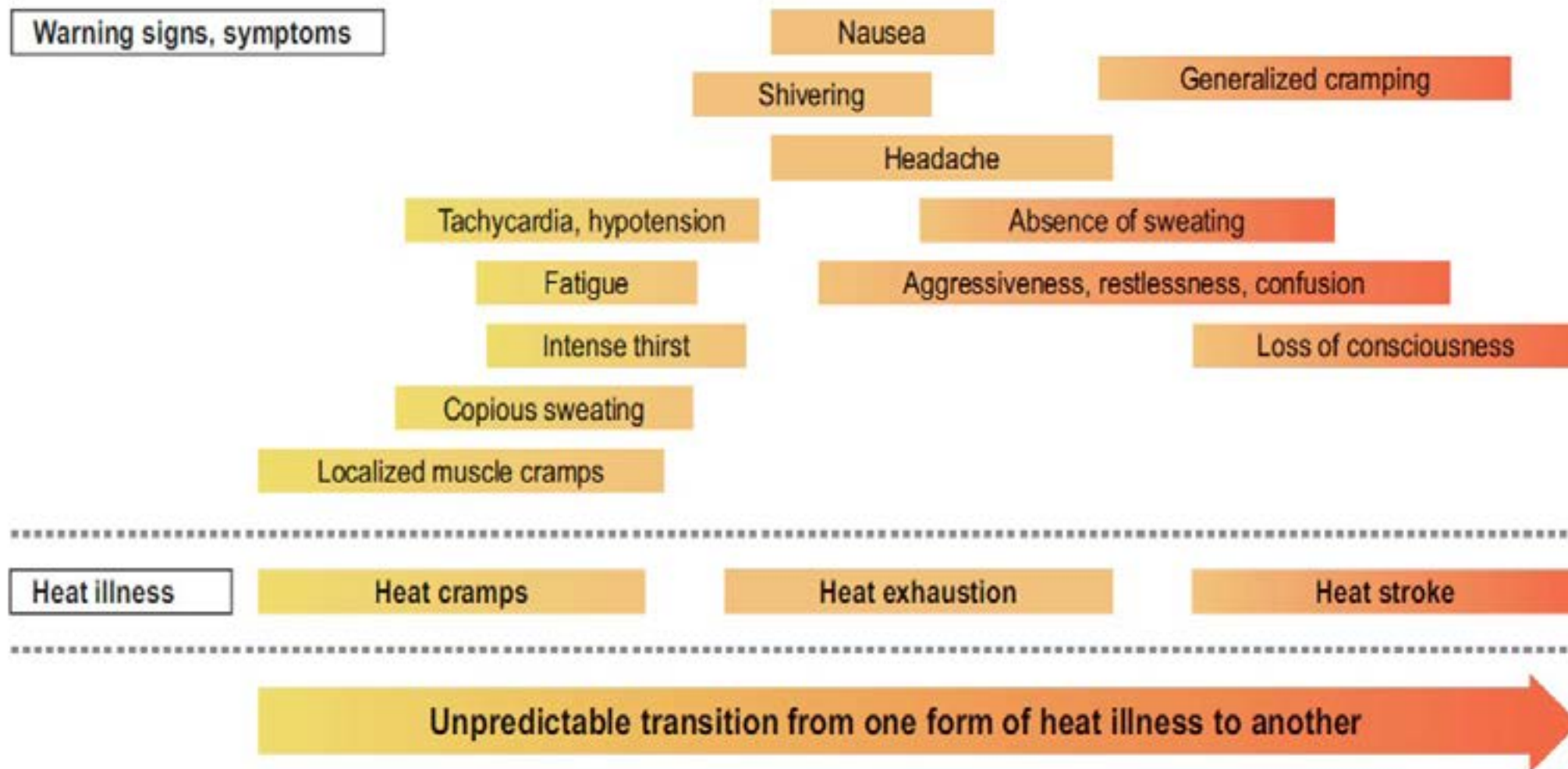
Heat Exhaustion

- Nausea or irritability
- Dizziness
- Muscle Cramps or weakness
- Feeling faint
- Headache
- Fatigue
- Heavy sweating
- High body temperature

Heatstroke

- Hot, dry skin or profuse sweating
- Confusion
- Loss of consciousness
- Seizures
- Very high body temperature

Source: <https://ukhsa.blog.gov.uk/2020/06/24/covid-19-and-summer-temperatures/>

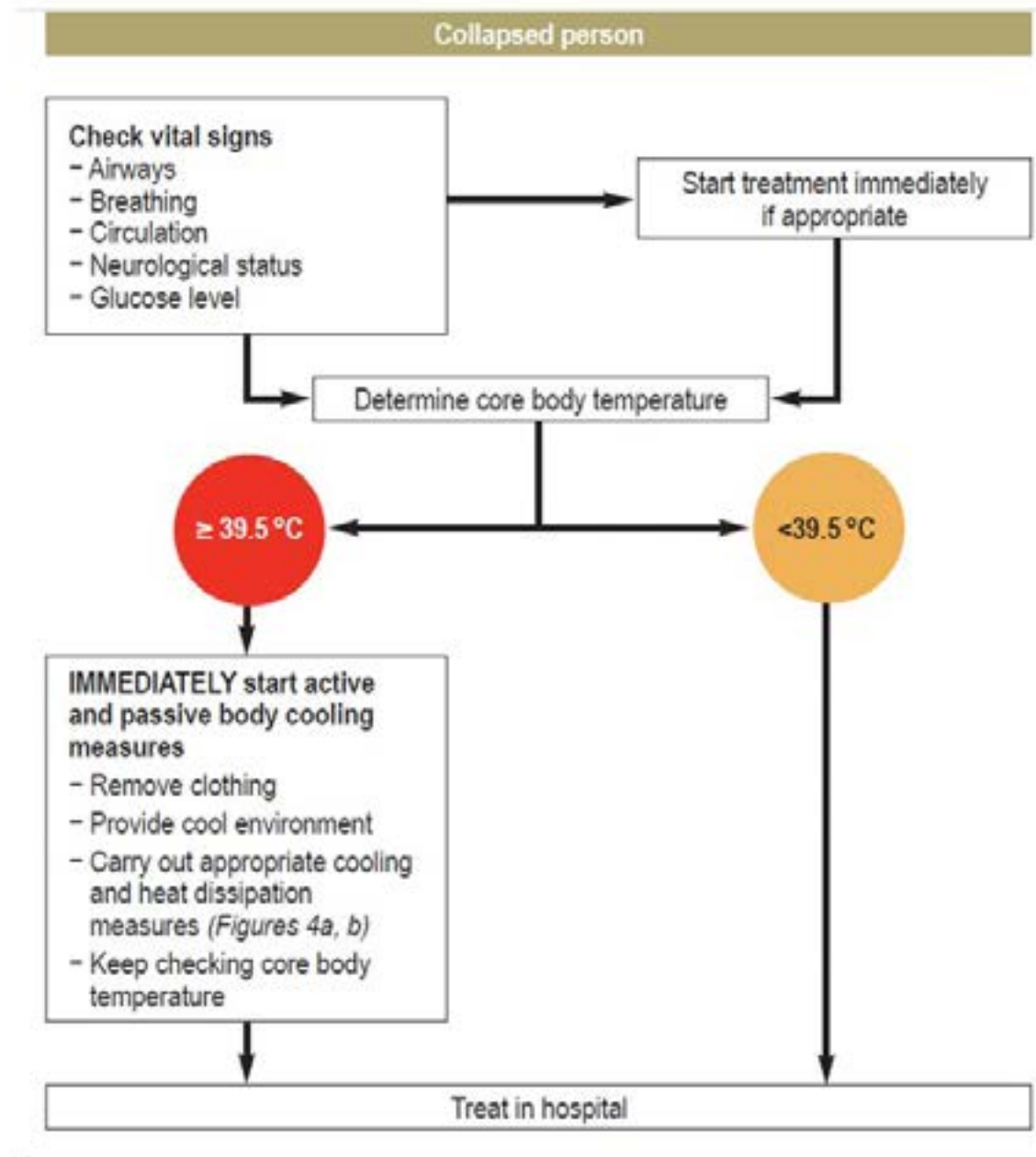


Symptoms of heat illness

Source: Leyk D et al.: Health Risks and Interventions in Exertional Heat Stress. doi: 10.3238/arztebl.2019.0537.

How can we recognise a heatstroke?

Flowchart for use in a case of suspected exertional heat stroke



Source: Leyk D et al.: Health Risks and Interventions in Exertional Heat Stress. doi: 10.3238/arztebl.2019.0537.

Comparison of high body temperature and acute infection

	Hypertermia	Acute infection
Body temperature:	high	High (shivering)
Skin temperature:	↑↑↑≥38.5°C, red, hot dry	↑↑↑≥38.5°C, wet, hot
Blood pressure:	low	Initially normal, later low
Infection parameters (CRP, BSG, Leukocytosis):	not elevated	elevated
Urine excretion	greatly reduced	Initially normal, later slightly decreasing
Response after adequate electrolyte and fluid intake:	rapid normalisation	Minimal improvement
Response to antipyretic medicine:	No or very slight improvement	Rapid improvement

Source: Public Health advice on preventing health effects of heat. WHO/EURO:2011-2510-42266-5869. <https://www.who.int/publications/i/item/public-health-advice-on-preventing-health-effects-of-heat>

Comparison of heat exhaustion and heat stroke

	Signs of heat exhaustion	Signs of heat stroke
Skin	cold and wet	red, hot and dry
Blood pressure	low	Initially normal, later low
Body temperature	Normal, later decreasing	Very high temperature >40°C, febrile convulsions possible
Pulse	tachycardia	Tachycardia, thready pulse
Gastro-intestinal symptoms	Loss of appetite, nausea, vomiting	nausea
Neurological symptoms	Weakness, dizziness, fatigue, collapse	Alternating headache, wakefulness and fainting (brain edema!) possible
Outcome	Rapid onset, short duration if properly intervened	Life-threatening condition, acute complications may develop

Source: Public Health advice on preventing health effects of heat. WHO/EURO:2011-2510-42266-5869. <https://www.who.int/publications/i/item/public-health-advice-on-preventing-health-effects-of-heat>

Mild and moderate heat illnesses and their management -1

Medical condition	Signs and symptoms/mechanisms	Management
Heat rash	<p>Small red itchy papules appear on the face, neck, upper chest, under breast, groin and scrotum areas.</p> <p>This can affect any age but is prevalent in young children.</p> <p>Infection with Staphylococcus can occur.</p> <p>It is attributed to heavy sweating during hot and humid weather.</p>	<p>Minimize sweating by staying in an airconditioned environment, taking frequent showers and wearing light clothes. Keep the affected area dry.</p> <p>Topical antihistamine and antiseptic preparations can be used to reduce discomfort and prevent secondary infection.</p>
Heat oedema	<p>Oedema of the lower limbs, usually ankles, appears at the start of the hot season.</p> <p>This is attributed to heat-induced peripheral vasodilatation and retention of water and salt.</p>	<p>Treatment is not required as oedema usually subsides following acclimatization. Diuretics are not advised.</p>
Heat syncope	<p>This involves brief loss of consciousness or orthostatic dizziness. It is common in patients with cardiovascular diseases or taking diuretics, before acclimatization takes place.</p> <p>It is attributed to dehydration, peripheral vasodilatation and decreased venous return resulting in reduced cardiac output.</p>	<p>The patient should rest in a cool place and be placed in a supine position with legs and hips elevated to increase venous return.</p> <p>Other serious causes of syncope need to be ruled out.</p>

Source: Public Health advice on preventing health effects of heat.
WHO/EURO:2011-2510-42266-5869.
<https://www.who.int/publications/i/item/public-health-advice-on-preventing-health-effects-of-heat>

Mild and moderate heat illnesses and their management- 2.

Medical condition	Signs and symptoms/mechanisms	Management
Heat cramps	<p>Painful muscular spasms occur, most often in the legs, arms or abdomen, usually at the end of sustained exercise.</p> <p>This can be attributed to dehydration, loss of electrolytes through heavy sweating and muscle fatigue.</p>	<p>Immediate rest in a cool place is advised. Stretch muscles and massage gently. Oral rehydration may be needed, using a solution containing electrolytes.</p> <p>Medical attention should be sought if heat cramps are sustained for more than one hour.</p>
Heat exhaustion	<p>Symptoms include intense thirst, weakness, discomfort, anxiety, dizziness, fainting and headache.</p> <p>Core temperature may be normal, subnormal or slightly elevated (less than 40 °C). Pulse is thready with postural hypotension and rapid shallow breathing. There is no alteration of mental status. This can be attributed to water and/or salt depletion resulting from exposure to high environmental heat or strenuous physical exercise.</p>	<p>Move the patient to a cool shaded room or air conditioned place. The patient should be undressed.</p> <p>Apply cold wet sheet or spray cold water and use fan if available.</p> <p>Lay the patient down and raise his or her legs and hips to increase venous return. Start oral hydration. If nausea prevents oral intake of fluids, consider intravenous hydration.</p> <p>If hyperthermia above 39 °C or impaired mental status or sustained hypotension occurs, treat as heatstroke and transfer the patient to hospital.</p>

Source: Public Health advice on preventing health effects of heat. WHO/EURO:2011-2510-42266-5869.
<https://www.who.int/publications/i/item/public-health-advice-on-preventing-health-effects-of-heat>

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Management of life-threatening heatstroke

Condition	Intervention	Goal
<p>Exposure to heat stress (heatwave, summer season and/or strenuous exercise)</p> <p>Changes in mental status (anxiety, delirium, seizures, Coma)</p>	<p>Measure core temperature (rectal probe). If > 40 °C, move to a cooler place, remove clothing, initiate external cooling; cold packs on the neck, axillae and groin, continuous fanning (or keep ambulance windows open) while skin is sprayed with water at 25–30 °C. Position an unconscious patient on his or her side and clear airway. Administer oxygen 4 l/min. Give isotonic crystalloid (normal saline). Rapidly transfer to an emergency department.</p>	<p>Diagnose heatstroke.</p> <p>Lower core temperature to < 39.4 °C.</p> <p>Promote cooling by conduction; maintain currents of air.</p> <p>Promote cooling by evaporation.</p> <p>Minimize risk of aspiration.</p> <p>Increase arterial oxygen saturation to > 90%.</p> <p>Ensure volume expansion.</p>

Source: Public Health advice on preventing health effects of heat. WHO/EURO:2011-2510-42266-5869. <https://www.who.int/publications/i/item/public-health-advice-on-preventing-health-effects-of-heat>

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In-hospital treatment

Condition	Intervention	Goal
Hyperthermia	Confirm diagnosis with thermometer calibrated to measure high temperatures (40–47 °C). Monitor skin and rectal temperature; continue cooling.	Keep skin temperature > 30 °C. Stop cooling when rectal temperature is < 39.4 °C.
Seizures	Consider benzodiazepines.	Control seizures.
Respiratory failure	Consider elective intubation (for impaired gag and cough reflexes or respiratory function deterioration)	Protect airway and augment oxygenation (arterial oxygen saturation to > 90%).
Hypotension	Administer volume expanders, add vasopressors and consider central venous pressure monitoring	Increase mean arterial pressure > 60 mmHg, restore organ perfusion and tissue oxygenation (consciousness, urinary output, lactate level).
Rhabdomyolysis	Expand volume with normal saline, intravenous furosemide and mannitol or intravenous sodium bicarbonate. Monitor serum potassium and calcium and treat even modest hyperkalaemia.	Prevent myoglobin-induced renal injury. Promote renal blood flow and diuresis. Ensure urine alkalinization.
Post-cooling		Prevent life-threatening cardiac arrhythmia.
Multiple organ system dysfunction	Use nonspecific supportive therapy.	Aid recovery of organ function.

Source: Public Health advice on preventing health effects of heat. WHO/EURO:2011-2510-42266-5869.
<https://www.who.int/publications/i/item/public-health-advice-on-preventing-health-effects-of-heat>

Take home messages

- A range of mild to severe health impacts can result from exposure to high temperatures. Especially when temperatures remain high for prolonged periods.
- The main causes of illness and death during a heatwave are respiratory and cardiovascular diseases.
- There are specific heat-related health effects and illnesses including: Heat cramps, heat rash, heat oedema, heat syncope, heat exhaustion, heatstroke.

Take home messages

What should you do about Heat Illness:

- If mild, hydrate and get out from heat
- If more severe (heat exhaustion), hydrate, cool, move to a cooler location
- If heat stroke, follow the guidelines of special emergency care

„Must read” literature

- IPCC-AR/ Technical Report
https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_TechnicalSummary.pdf
- The health impacts of hot weather and the Heatwave Plan for England https://www.hcpa.info/wp-content/uploads/2018/06/The-health-impacts-of-hot-weather-and-the-Heatwave-Plan-for-England_fina....pdf
- *Balmain BN, Sabapathy S, Louis M, Morris NR. Aging and Thermoregulatory Control: The Clinical Implications of Exercising under Heat Stress in Older Individuals. Biomed Res Int. 2018 Aug 2;2018:8306154. doi: 10.1155/2018/8306154.*
- González-Alonso J. Human thermoregulation and the cardiovascular system. *Exp Physiol.* 2012 Mar;97(3):340-6. doi: 10.1113/expphysiol.2011.058701
- Rublee C, Dresser C, Giudice C, Lemery J, Sorensen C. Evidence-Based Heatstroke Management in the Emergency Department. *West J Emerg Med.* 2021 Feb 26;22(2):186-195. doi: 10.5811/westjem.2020.11.49007. PMID: 33856299; PMCID: PMC7972371.
- Leyk D, Hoitz J, Becker C, Glitz KJ, Nestler K, Piekarski C. Health Risks and Interventions in Exertional Heat Stress. *Dtsch Arztebl Int.* 2019 Aug 5;116(31-32):537-544. doi: 10.3238/arztebl.2019.0537. PMID: 31554541; PMCID: PMC6783627
- Public Health advice on preventing health effects of heat. WHO/EURO:2011-2510-42266-5869. <https://www.who.int/publications/i/item/public-health-advice-on-preventing-health-effects-of-heat>

Test your knowledge

- What is the major climate related health hazard in Europe?
- Who are at risk of extreme heat?
- What are the ways of heat exchange?
- How can you describe the physiology of temperature control?
- Which factors do contribute to increased risk of heat illness in aging?

Test your knowledge

- You can you differentiate heat illness from infectious diseases?
- How can you set up a diagnosis of heat stroke
- How can you treat moderate heat illness?
- How can you treat serious heat stroke?

Thank you for you attention!

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University of Pécs Medical School – Pécs, Hungary



Center for Health, Exercise and Sport Science – Novi Sad, Serbia



National Public Health Center – Budapest, Hungary



University College Cork – National University of Ireland – Cork, Ireland



Universitatea de Medicina, Farmacie, Stinte si Tehnologie
George Emil Palade din Tirgu Mures – Tirgu Mures Romania

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Impact of Climate Change on Cardiovascular Disease

Learning outcomes

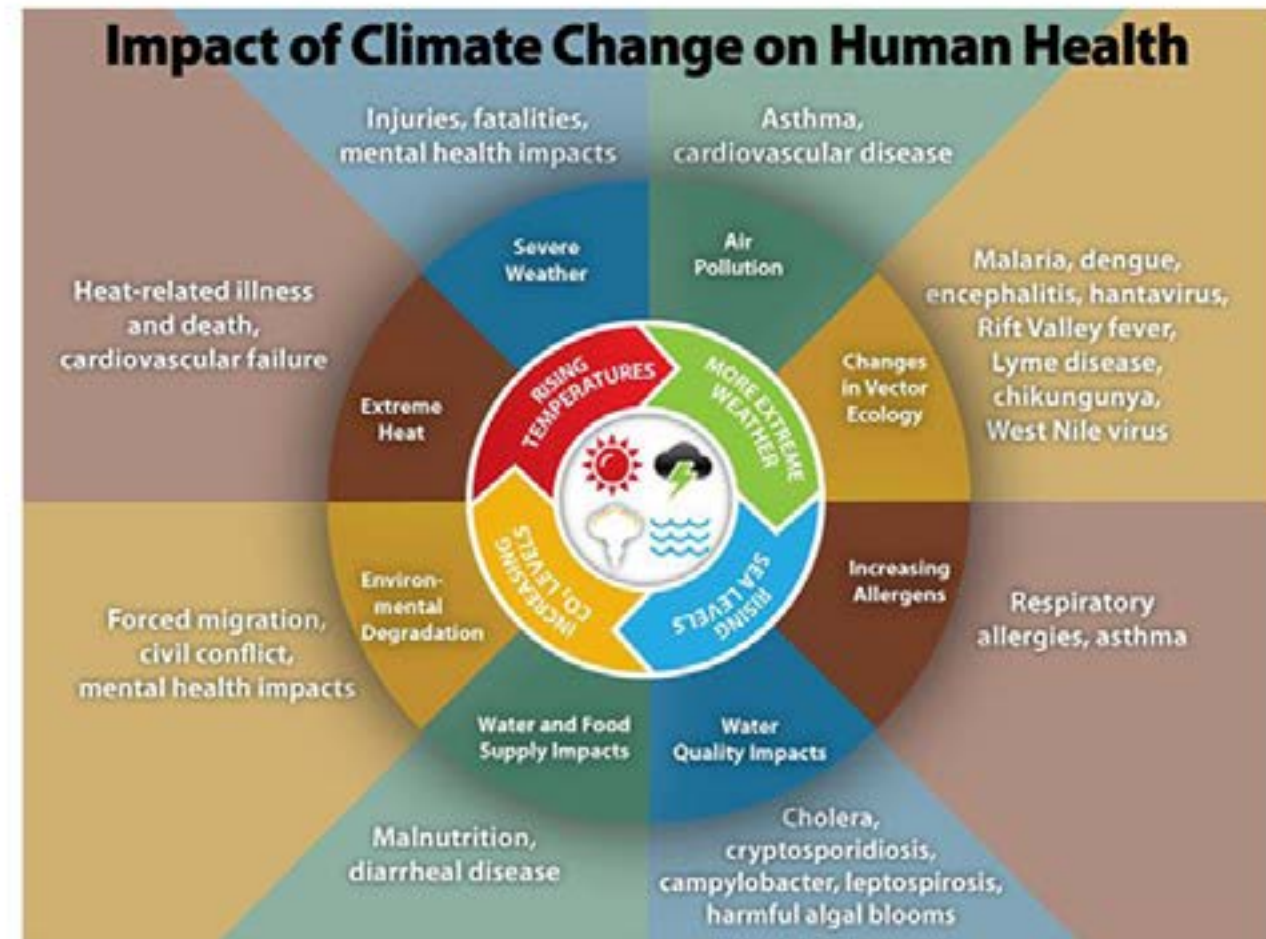
Upon successful completion of the lesson, students will be able to:

- Describe the interconnections between accelerating global emergency: climate change and cardiovascular disease (CVD)
- Understand how air temperature, air pollution, wildfires, and desert dust impact CVD
- Identify subpopulations that are particularly vulnerable to climate change-related effects on CVD
- Discuss how to mitigate climate change-related CVD
- Identify actions health professionals can take to prepare populations with compromised cardiovascular health for extreme weather events and natural disasters

Climate Change and CVD

Climate change (CC) is the greatest existential challenge to planetary and human health.

Among many effects, climate change impacts the CVD and overall health, and this represents a multifaceted problem that needs to be urgently addressed at various levels.



Impact of Climate Change on Human Health.

Source: https://www.cdc.gov/climateandhealth/images/climate_change_health_impacts600w.jpg?_t=06389

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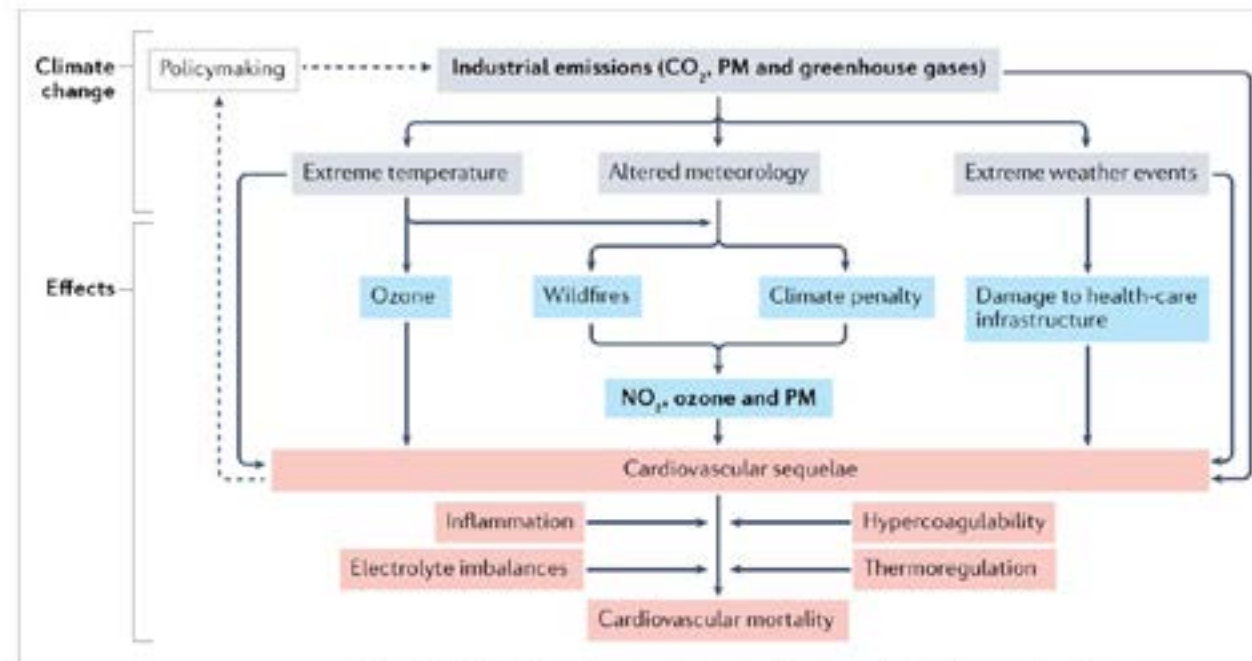
- Climate change (CC) is the greatest existential challenge to planetary and human health.
- Among many effects, climate change impacts the CVD and overall health, and this represents a multifaceted problem that

needs to be urgently addressed at various levels.

- For example, in 2019, approximately 18.6 million people died from CVD worldwide and the CVD remains the leading cause of death globally.

- Accordingly, it is necessary to uncover the connections that exist between CC and other stressors and CVD in order to develop mitigation and prevention strategies.

Climate Change and CVD



The effect of climate change on the development of cardiovascular disease.

Source: from Kharabeh et al., 2022

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Direct exposure to extreme weather events, ambient temperatures, heat waves, cold spells and a wide array of pollutants has the potential to exacerbate disease in individuals with underlying CVD conditions and contribute to the development of disease in those without known CVD.

The most plausible mechanisms seem to relate to extremes in weather patterns and air pollution, each of which might have independent yet interlinked effects on cardiovascular health.

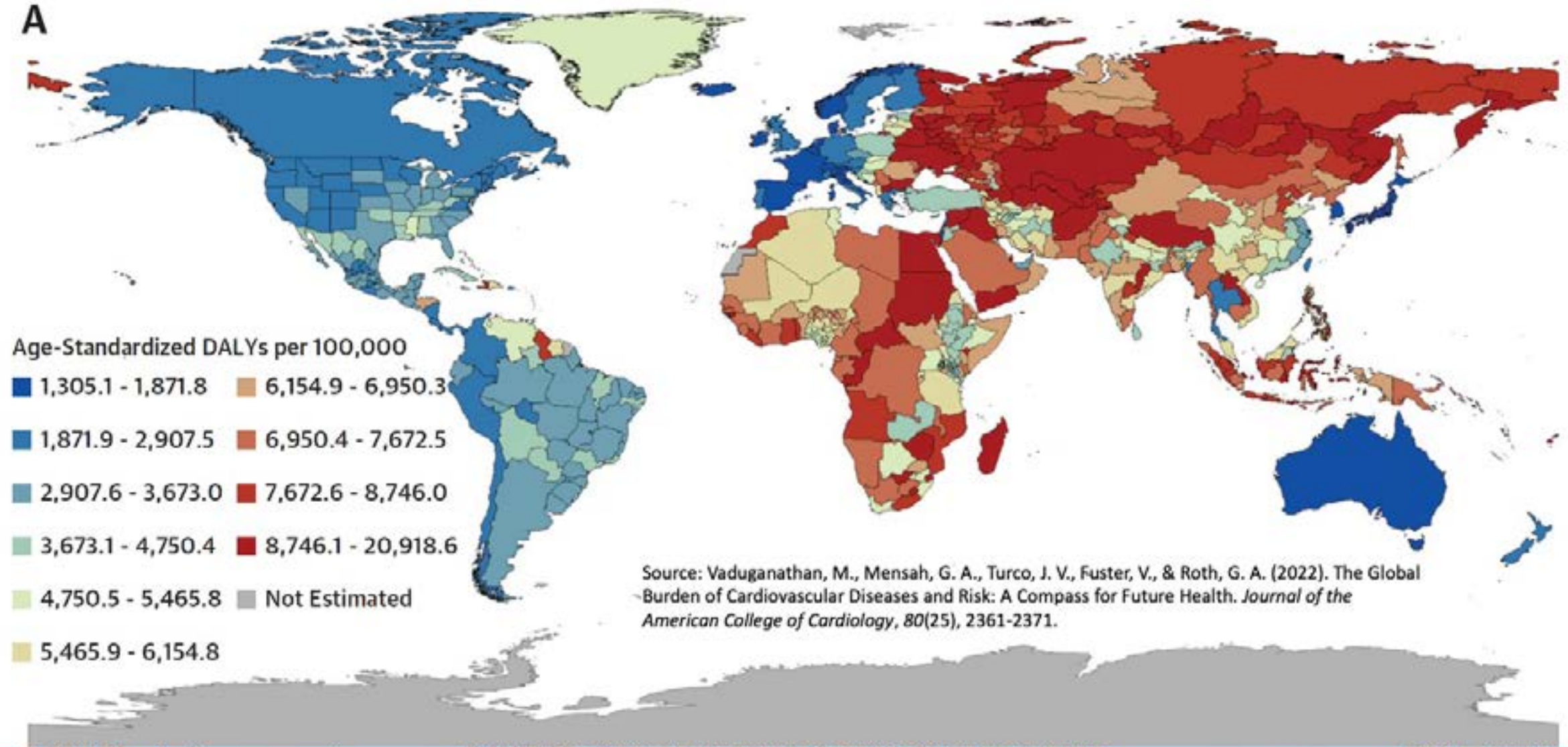
→ Worsening air quality owing to increased pollutants can exacerbate the extreme fluctuations in temperature levels, and these

changes might lead to further deteriorations in air quality.

In addition, the indirect effects of CC on cardiovascular health involve multiple complex exposure pathways including access to healthy food and clean water, transportation, housing, electricity, communication systems, medical assistance and other social determinants of health, all of which are essential for the maintenance of cardiovascular health.

CENTRAL ILLUSTRATION Global Burden of Cardiovascular Diseases and Risks

A

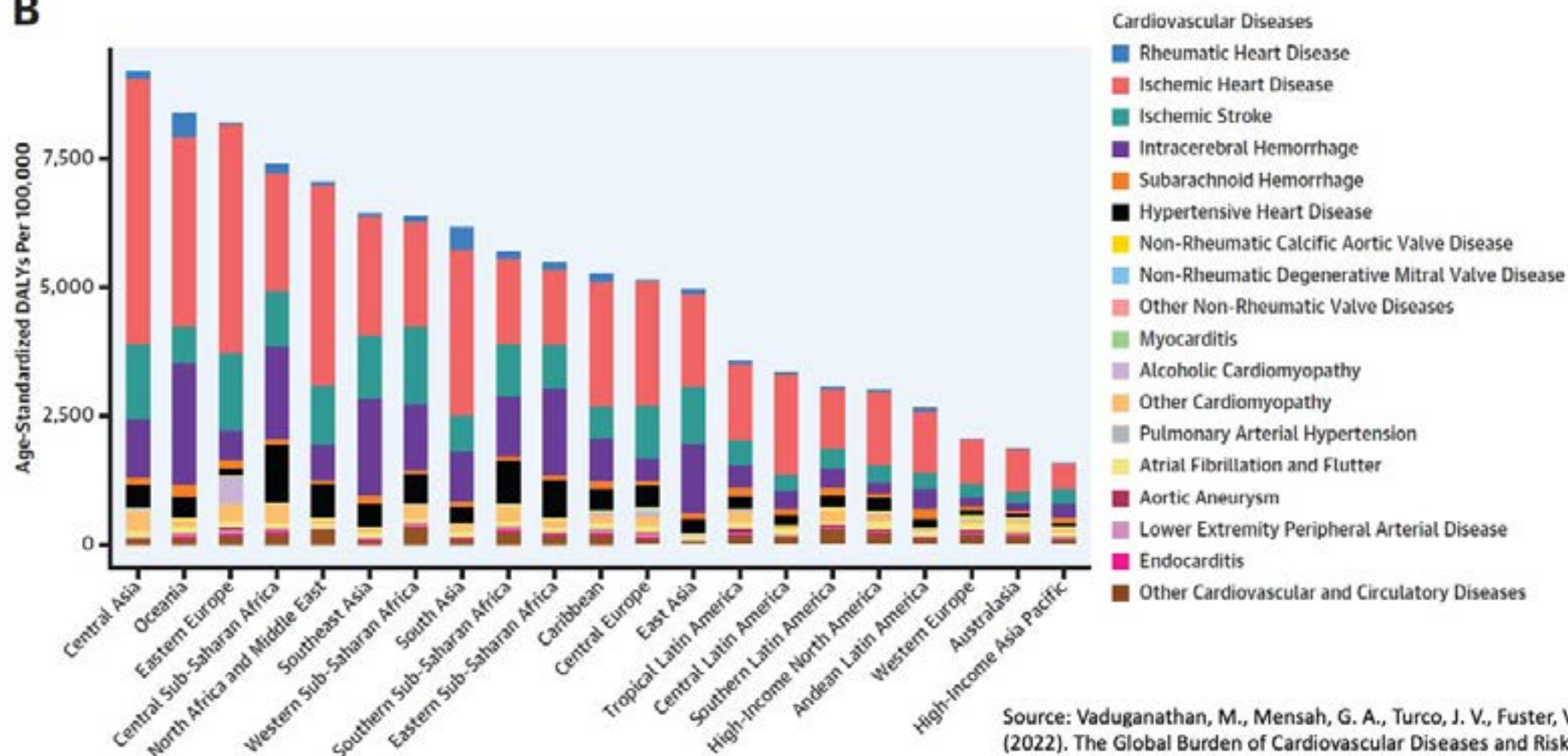


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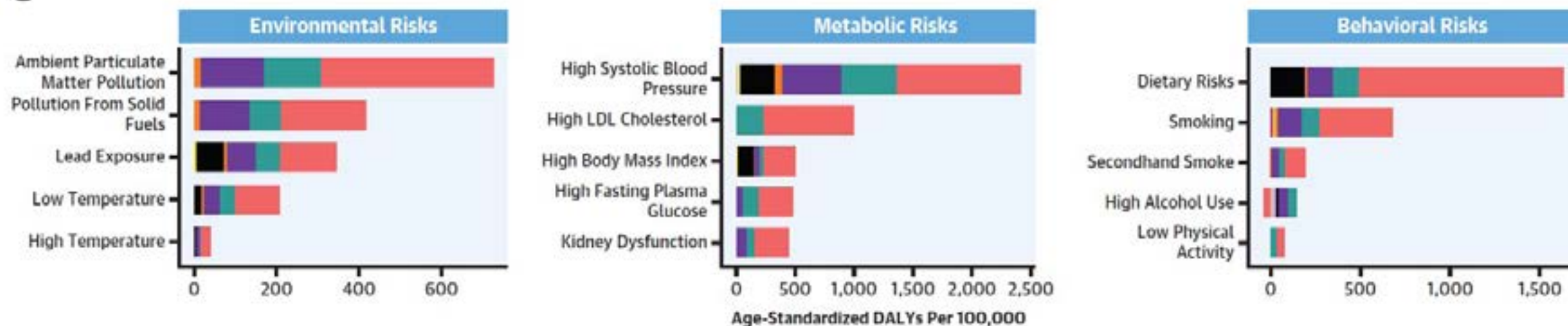
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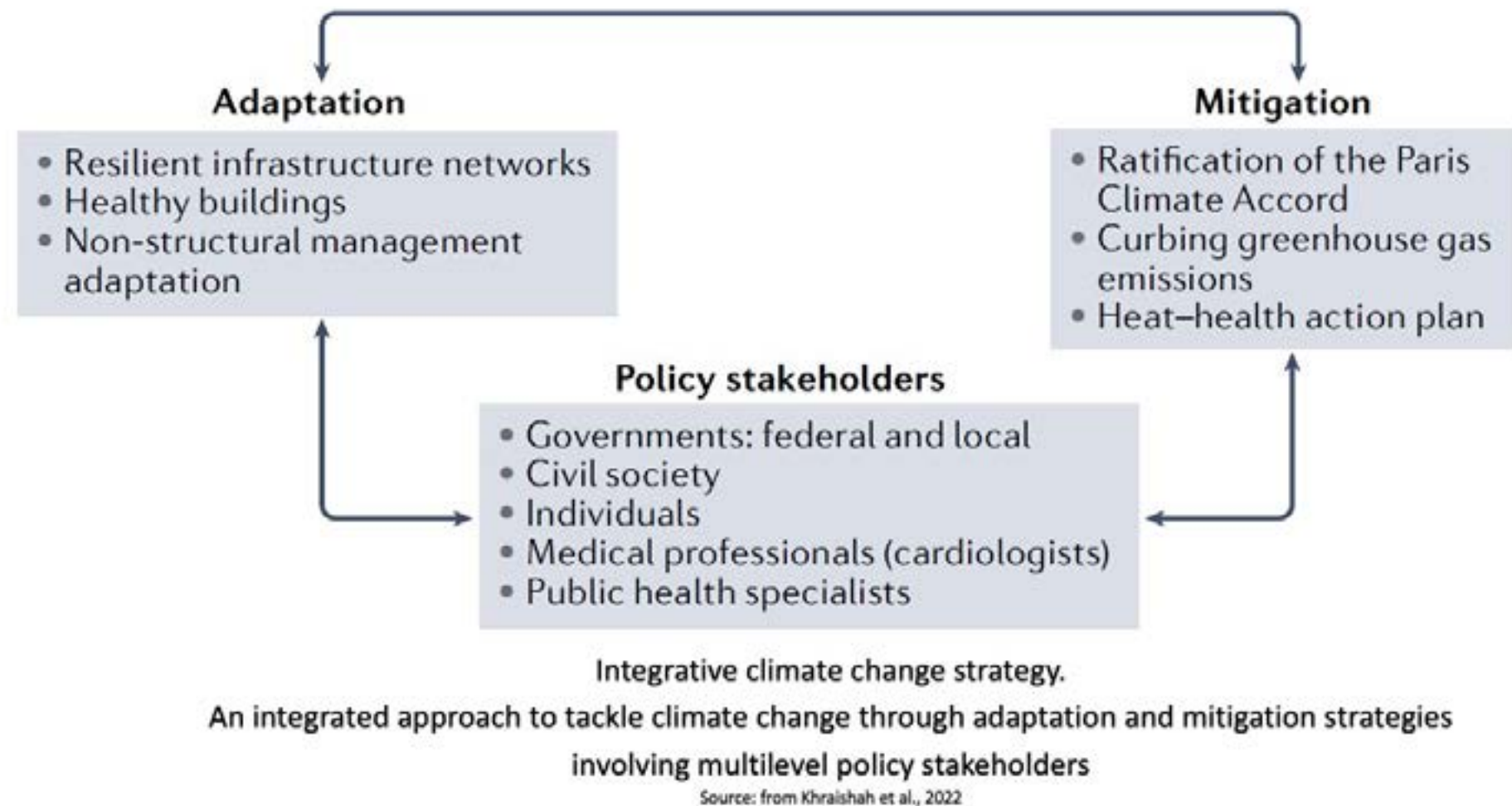
Source: Vaduganathan, M., Mensah, G. A., Turco, J. V., Fuster, V., & Roth, G. A. (2022). The Global Burden of Cardiovascular Diseases and Risk: A Compass for Future Health. *Journal of the American College of Cardiology*, 80(25), 2361-2371.

C



Source: Vaduganathan, M., Mensah, G. A., Turco, J. V., Fuster, V., & Roth, G. A. (2022). The Global Burden of Cardiovascular Diseases and Risk: A Compass for Future Health. *Journal of the American College of Cardiology*, 80(25), 2361-2371.

Climate Change and CVD

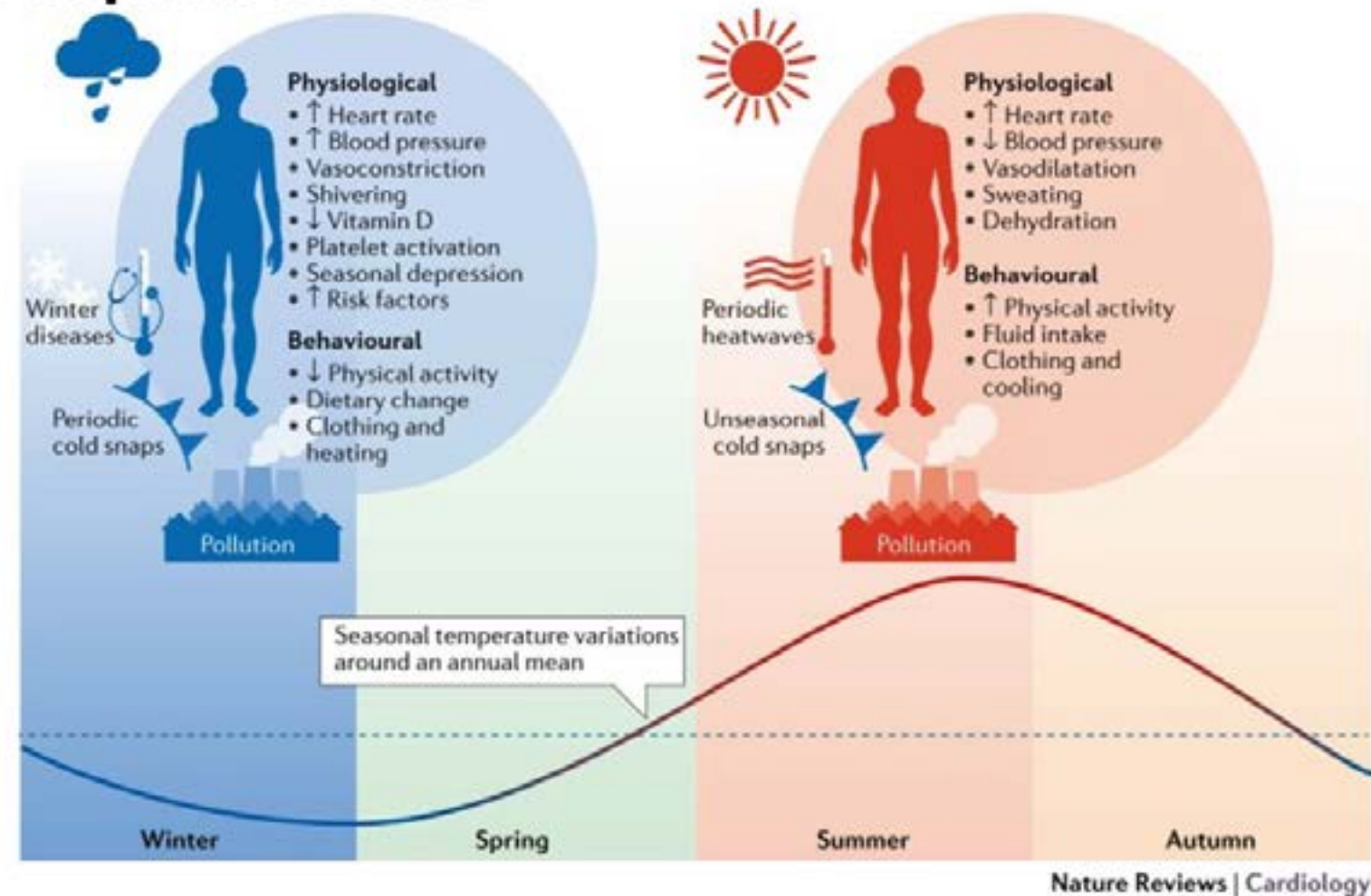


In the lesson, we will learn about connections between:

- air temperature (heat waves and cold spells) and CVD,
- air pollution (particulate matter and ozone) and CVD,

- wildfires, desert dust and CVD, as well as about
- vulnerable subpopulations,
- how to mitigate climate change-related CVD,
- and will provide some take-home messages for physicians and cardiologists.

Air temperature impacts on CVD



Model of seasonal variation in cardiovascular disease:
individual–environmental interactions

Source: from Stewart et al., 2017

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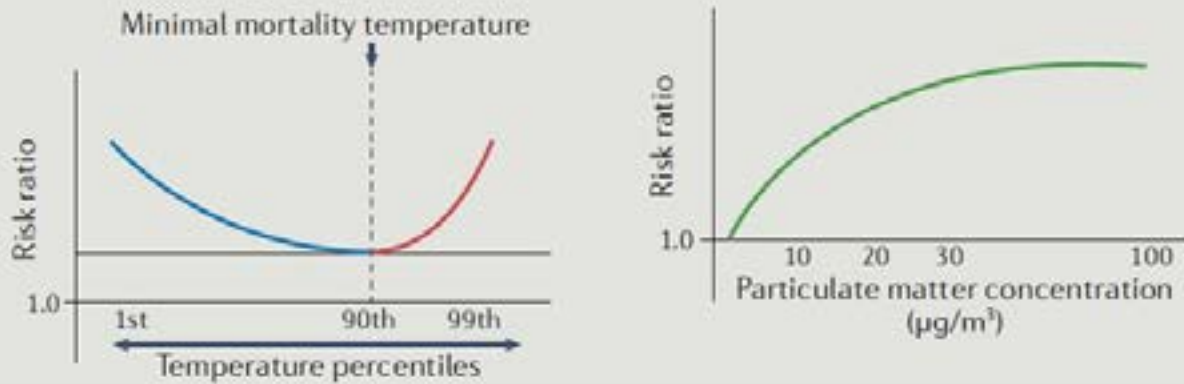
Both low and high temperatures contribute to cardiovascular morbidity and mortality.

In 2019, the Global Burden of Disease Study introduced non-optimal temperatures as a risk factor for death worldwide, with the greatest mortality burden associated with low rather than high temperatures.

A 2021 global analysis estimated that >5 million deaths annually are associated with non-optimal temperatures.

These trends are expected to worsen in the coming years given continual global warming and greater vulnerability of patients with multiple risk factors for CVD⁶¹.

Air temperature impacts on CVD

Feature	Ambient temperature	Particulate matter
Unit of measurement	Degrees Fahrenheit or Celsius	Micrograms per cubic metre
Exposure assessment	Average daily outdoor air temperature, usually measured from meteorological stations	Average daily particulate matter (PM _{2.5} and PM ₁₀) levels, usually measured by regulatory monitoring networks or estimated from models with fine spatiotemporal resolution
Study design	Time-series and case-crossover studies for short-term effects; longitudinal cohort studies for long-term effects	Time-series and case-crossover studies for short-term effects in time-series and case-crossover studies; longitudinal cohort studies for long-term effects
Lag effect	Cold temperatures up to 3 weeks; hot temperatures up to 1 week	Up to 5 days (short-term effects)
Exposure-response curve		

PM_{2.5}, fine particulate matter ≤2.5 µm in diameter; PM₁₀, particulate matter ≤10 µm in diameter.

Temperature and particulate matter as climate change-related health exposures

Source: from Khraishah et al., 2022

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- The effect of short-term exposure to temperature fluctuations on mortality showed that the exposure-response relationship is inherently non-linear and might produce U-shaped, V-shaped or J-shaped curves.
- Optimum temperature (which refers to the mean daily temperature at which the

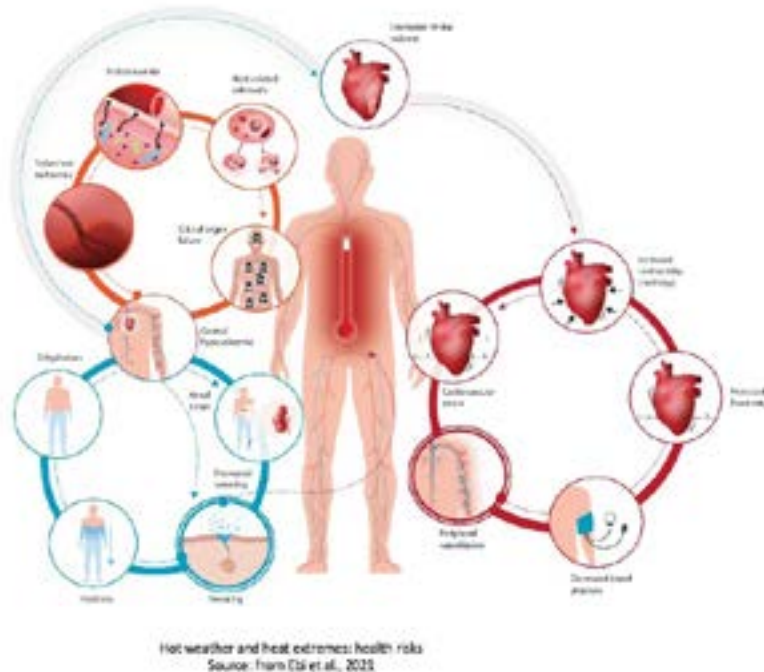
lowest mortality occurs and is also known as the minimum mortality temperature) is the demarcation or the inflexion point of the curves and can vary according to climate zone, geographical location and population vulnerabilities.

- Another actor to consider is the delayed or 'lagged' effect over time of environmental

stressors, such as extreme temperature or air pollution.

- The health effects of exposure to extreme cold temperature usually persist longer (up to 2 weeks or more) than the effects of exposure to extreme heat events, which normally last for 2-3 days.

Epidemiology of temperature-related CVD: Cardiovascular risk factors



Source: <https://www.englishinstituteofsport.com/news/sleeping-in-the-heat>

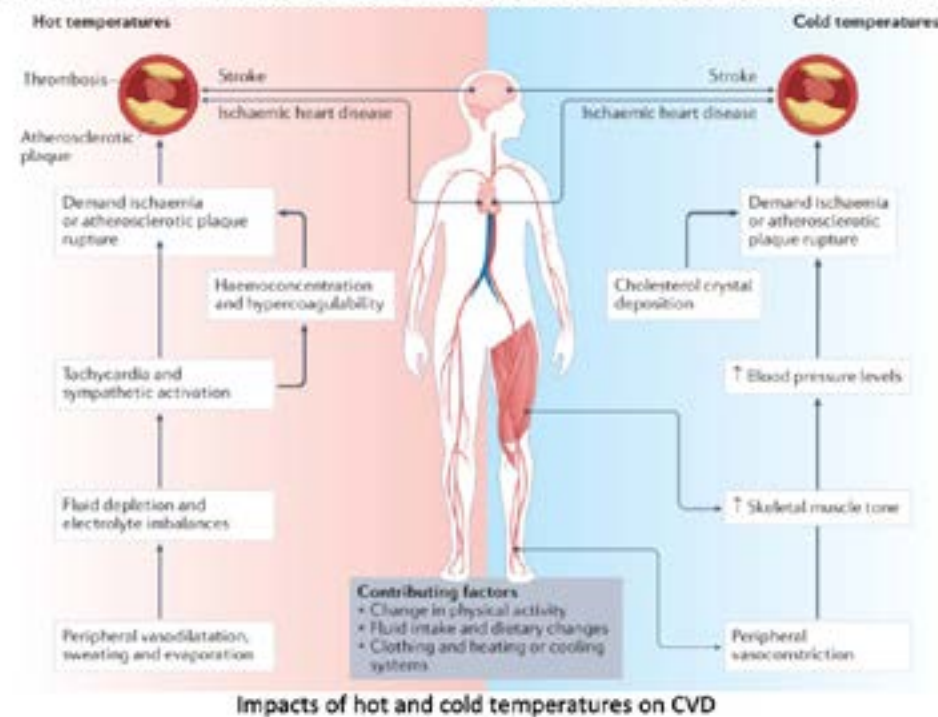
- Temperature extremes might have an influence on the risk of developing diabetes and might also be associated with poor glycaemic control in patients with underlying diabetes.
- Short-term fluctuations in temperature have also been linked with blood pressure levels.
 - Studies across a range of climates and populations have demonstrated an inverse association between temperature and blood pressure levels on the same and/or preceding days.
- Studies showed that a decrease in mean outdoor temperature of 1 °C was associated with an increase in systolic blood pressure of

0.26 mmHg and in diastolic blood pressure of 0.13 mmHg.

- Interestingly, night-time blood pressure has been shown to be higher during the summer months than in the winter months, suggesting that a warming climate might have opposing effects and counteract traditional mechanisms of cardio protection.
- Warmer nights might lead to increased blood pressure levels several hours later during the following afternoon.
- Reduced sleep duration or quality has also been suggested as a potential mechanism for the seemingly paradoxical elevation in night-time blood pressure levels during warmer weather.

- In addition, increases in mean ambient temperature were associated with lower plasma HDL and higher plasma LDL levels.
- Higher temperatures are associated with less time spent exercising, which can potentially increase the risk of CVD in the long term.

Epidemiology of temperature-related CVD: Cardiovascular mortality



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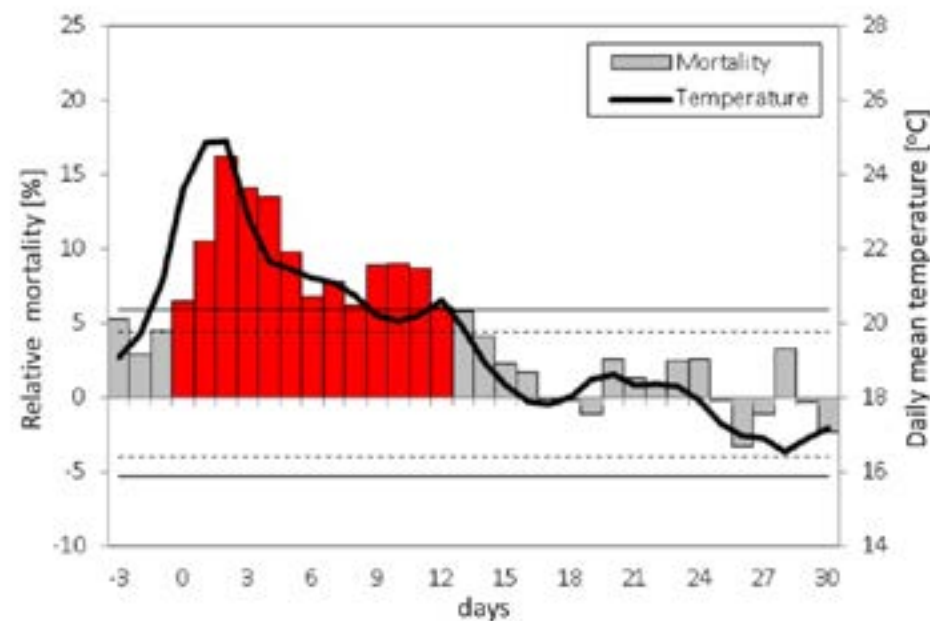
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- The relative risk of all-cause death and cardiovascular death increases sharply if the mean daily temperature goes above or below the optimum temperature.
- A 1 °C increase or decrease in ambient temperature above or below the optimal temperature threshold was associated with an increase in cardiovascular mortality of 3.44% and 1.66%, respectively.
 - A time-series analysis in England and Wales during the summer months for the period 1993–2006 demonstrated an increase in cardiovascular mortality by 1.8% for every 1 °C increase above the regional heat threshold.

- A time-series analysis of individuals from >270 Chinese cities assessed during 2013–2015 demonstrated that cold temperatures had a greater association with cardiovascular mortality than high ambient temperatures.
 - Compared with the optimum temperature, extreme cold temperatures were associated with an increase in cardiovascular mortality of 92%, with sustained effects lasting >14 days.
 - Conversely, extreme hot temperatures were associated with an increase in cardiovascular mortality of 22%.

Epidemiology of temperature-related CVD: Ischaemic heart disease



Influence of Heat Waves on Ischemic Heart Diseases in Germany

Source: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3724702/>

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High and low temperature extremes are associated with an increased incidence of MI.

- The relationship between cold temperatures and MI hospitalization has been well described in the literature, the association between heat and MI hospitalization is less consistent.

A study from Augsburg, Germany, compared the incidence of MI during the periods of 1987–2000 and 2001–2014:

- During the earlier period, MI was triggered by cold exposure only, but the relative risk of heat-related MI significantly increased during the latter period.

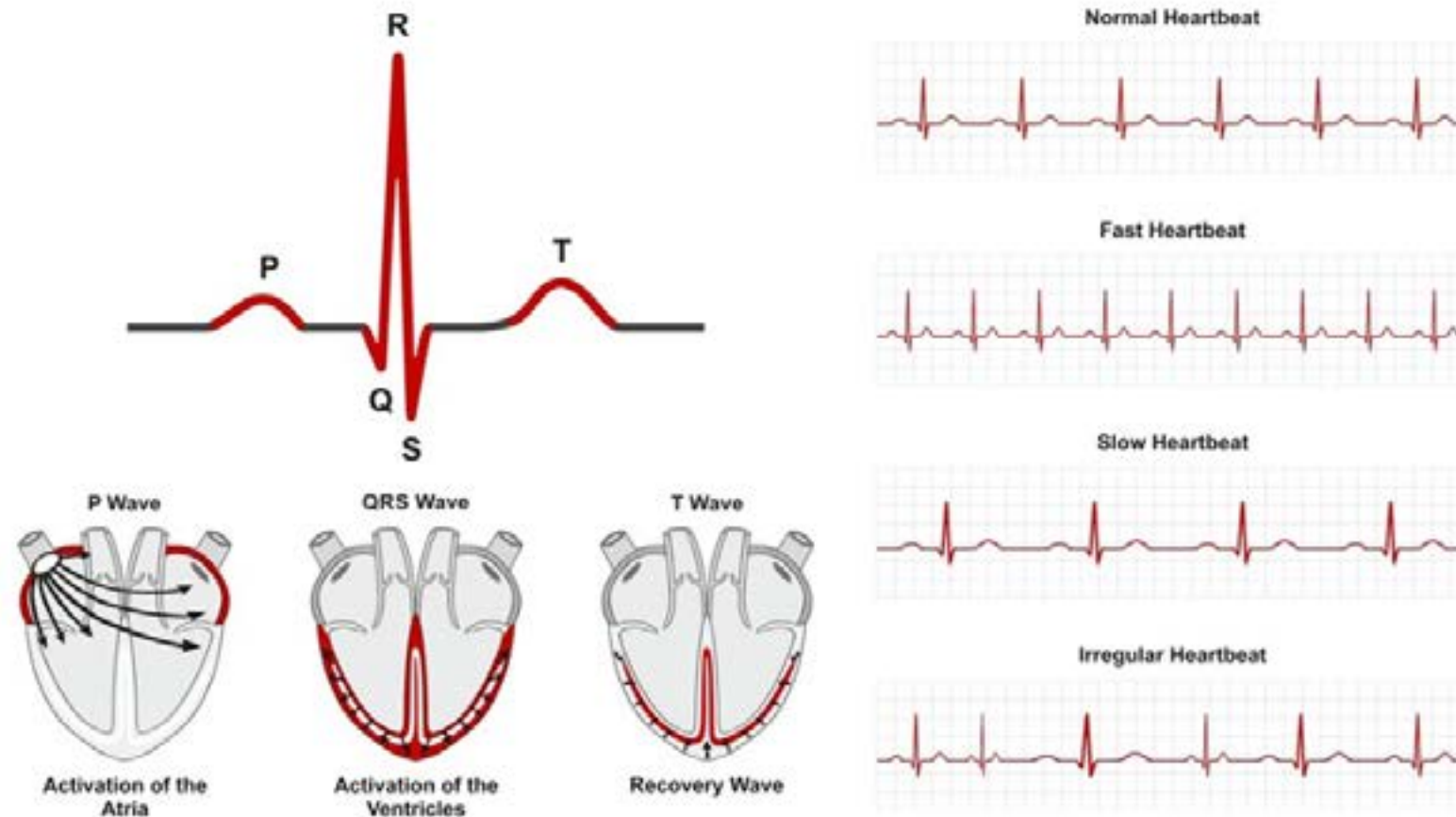
- The increased susceptibility to heat was more evidence in patients with diabetes and hyperlipidaemia, underscoring the importance of depicting non-optimal temperature as a risk factor for CVD, especially in vulnerable subgroups⁸⁹.

Some studies did not find an association between warmer temperatures and an increased incidence of MI in Madrid, Spain, and in England and Wales.

However, a meta-analysis of 23 studies showed that the relative risk of MI hospitalization was 1.016 for each 1 °C increase in ambient temperature and 1.014 for each 1 °C decrease.

Epidemiology of temperature-related CVD: HF admissions and Arrhythmias

Normal and Abnormal Heart Rate



Source: <https://www.carolinaheartandleg.com/wp-content/uploads/2018/04/ARRHYTHMIA.jpg>

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Numerous studies showed greater HF admissions and mortality during winter months, concomitant with an increase in mortality related to respiratory diseases.

A greater diurnal temperature range (the difference between the maximal and minimal

temperatures in a single day) has also been linked to greater HF admissions.

A study of >30,000 arrhythmia-related emergency department visits in Seoul, South Korea, found that each 1 °C decrease in mean temperature and each 1 °C increase in diurnal temperature range was associated with an

increase in the attributable risk of cardiac arrhythmias by 1.06% and 1.84%, respectively.

In a subgroup analysis, women and older individuals aged ≥65 years were more susceptible to changes in diurnal temperature range than their male and younger counterparts, respectively.

Epidemiology of temperature-related CVD: Stroke

In terms of the **incidence of stroke**, no association was found between hot temperatures and stroke in a meta-analysis of 20 studies, whereas low temperatures increased the risk of stroke by 0.9%.



Source: <https://www.express.co.uk/life-style/health/852809/heart-disease-flu-cold-winter>

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Studies of the association between stroke (and its subtypes) and ambient temperature have yielded inconsistent findings.

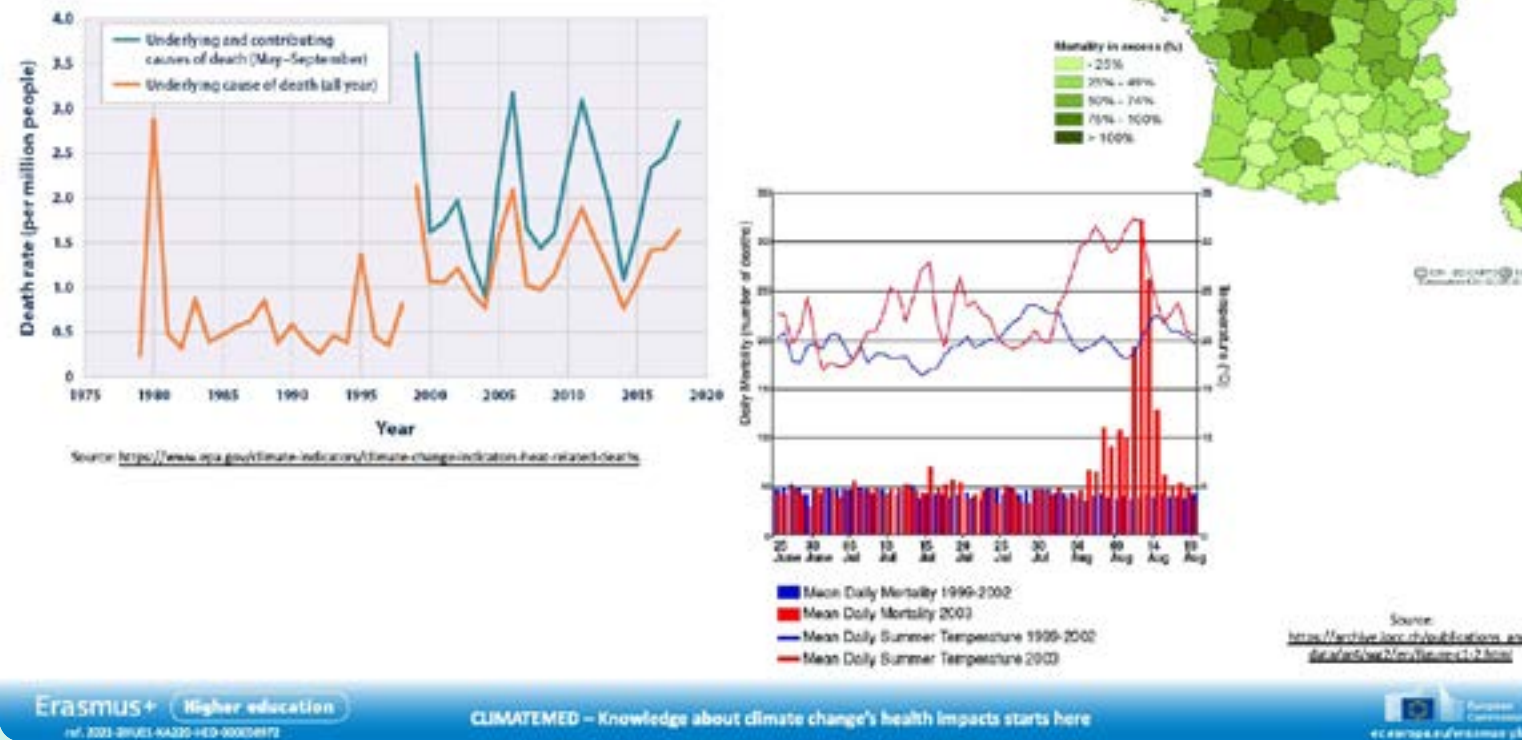
In a systematic review and meta-analysis of 20 studies and about 2,000,000 events, an increase or a decrease of 1 °C in ambient

temperature increased the risk of stroke-related death by 1.5% and 1.2%, respectively.

→ As with other cardiovascular outcomes, the effects of cold weather occurred 2–4 days after the exposure, whereas the effects of heat occurred on the same day.

Another study demonstrated that lower temperatures were significantly correlated with higher risks of all subtypes of stroke but found substantial heterogeneity in the magnitude of the effect depending on the geographical latitude and average temperatures at the study site.

Effect of heatwaves and cold spells on CVD



This figure shows the annual rates for deaths classified as “heat-related” by medical professionals in the 50 states and the District of Columbia. The orange line shows deaths for which heat was listed as the main (underlying) cause.* The blue line shows deaths for which heat was listed as either the underlying or contributing cause of death during the months from May to September, based on a broader set of data that became available in 1999.

Although heatwaves are not a new phenomenon, their intensity, frequency and duration are expected to increase owing to climate change.

In a meta-analysis that pooled the effects of heatwaves on all-cause and cardiorespiratory

mortality using different heatwave definitions, a heatwave of $\geq 35^{\circ}\text{C}$ for ≥ 3 days revealed a 21% increased risk of cardiovascular death.

Another meta-analysis studies found that heatwaves increased cardiovascular mortality by 15%.

Conversely, pooling of 18 studies (with different definitions of a heatwave) revealed no association between heatwaves and cardiovascular morbidity.

The heatwaves in July 1995 in Chicago, USA, and in the summer of 2003 in Europe were pivotal in providing insights into the adverse health effects of heatwaves.

In Chicago, the 8-day heatwave event in July 1995 resulted in >600 excess deaths and 3,300 emergency room visits.

→ An 11% increase in hospital admissions in Chicago owing to dehydration, heat stroke and heat exhaustion was observed, especially in patients with underlying CVD (such as hypertension) and diabetes.

During the European heatwave in July and August of 2003, temperatures ranging from 35°C to 40°C were repeatedly recorded across multiple Western and Central European countries.

An analysis from 16 European countries found 70,000 additional deaths during the summer of 2003 compared with summer reference periods for the period 1998–2002.

Cold spells are defined by a low temperature threshold lasting for a specific duration (usually >2 consecutive days).

Studies found that cold spells were associated with an 11% increase in cardiovascular mortality.

According to data from the British Regional Heart Study, cold spells increased the risk of death related to coronary heart disease or stroke twofold.

Several meteorological variables can contribute to heat and cold vulnerability, including humidity, wind and solar radiation.

Morbidity and mortality can increase with increasing temperature, in part owing to the associated increase in humidity levels, which places stress on the thermoregulatory system.

Air pollution impacts on CVD: Particulate Matter (PM)

2005 V.S. 2021 WHO air quality guidelines (AQGs)
Preventable PM_{2.5} deaths avoided if new AQGs met globally: ~80% Source: WHO

Pollutant	Averaging Time	2005 AQGs	2021 AQGs
PM _{2.5} $\mu\text{g}/\text{m}^3$	Annual 24-hour	10 25	5 15
PM ₁₀ $\mu\text{g}/\text{m}^3$	Annual 24-hour	20 50	15 45
Ozone (O ₃) $\mu\text{g}/\text{m}^3$	Peak Season* 8-hour**	- 100	60 100
Nitrogen dioxide (NO ₂) $\mu\text{g}/\text{m}^3$	Annual 24-hour*	40 -	10 25
Sulfur dioxide (SO ₂) $\mu\text{g}/\text{m}^3$	24-hour	20	40
Carbon monoxide (CO) mg/m^3	24-hour*	-	4

WHO air quality guidelines from 2021

Source: <https://www.who.int/news-room/2021-who-air-quality-guidelines>

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A sizeable body of evidence exists on the effects of air pollution on cardiovascular and cardiometabolic morbidity and mortality.

Primary air pollutants are emitted from natural or anthropogenic sources directly into the atmosphere, whereas secondary pollutants result from the chemical reactions or the physical interactions between the primary pollutants themselves or with other atmospheric components.

Examples of primary pollutants include particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO₂) and nitrogen oxides such as nitrogen dioxide (NO₂)

Secondary pollutants include secondary PM_{2.5} and photochemical oxidants such as O₃.

The exposure-response curve between either ground O₃ or PM levels and health outcomes is hyperbolic, with sharp increases at lower exposure levels reaching a plateau at higher levels.

PM – usually measured in micrograms per cubic metre (mass per volume) by regulatory and monitoring networks, but sometimes estimated at finer spatial resolutions using remote sensing data – is a mixture of solid and liquid substances that arise from natural sources (including crustal material such as sand and salt), agricultural sources (such as

ammonia-based fertilizer) and anthropogenic sources (such as the burning of fossil fuels).

PM can be categorized according to size:

- PM₁₀ refers to inhalable particles with an aerodynamic diameter of <10 μm (1 μm micrometre] = 0.001 mm),
- PM_{2.5} to fine particles <2.5 μm and
- PM_{0.1} to ultrafine particles <0.1 μm
- PM size determines the fate and mode of transport of the particles, as well as their location within the respiratory tract where they will settle

Current evidence suggests that the level of PM_{2.5} exposure that can mediate adverse health effects is well below the levels of PM_{2.5} exposure recommended by the World Health Organization (WHO) air quality guidelines (<5 $\mu\text{g}/\text{m}^3$ for annual levels and <15 $\mu\text{g}/\text{m}^3$ for daily levels), with no evidence of a lower threshold below which PM_{2.5} levels are considered safe.

Stratospheric O₃ is a naturally occurring molecule in the Earth's stratosphere that acts as an important shield by absorbing ultraviolet radiation emitted by the sun.

Ground (tropospheric) O₃ is different from stratospheric O₃. At the ground level, O₃ is a major secondary pollutant, and its formation is promoted by photochemical reactions of nitrogen oxide and volatile organic compounds in a sunlit atmosphere.



Air pollution impacts on CVD: Particulate Matter (PM)

2005 V.S. 2021 WHO air quality guidelines (AQGs)
Preventable PM2.5 deaths avoided if new AQGs met globally: ~80% Source: WHO

Pollutant	Averaging Time	2005 AQGs	2021 AQGs
PM2.5 $\mu\text{g}/\text{m}^3$	Annual 24-hour	10 25	5 15
PM10 $\mu\text{g}/\text{m}^3$	Annual 24-hour	20 50	15 45
Ozone (O ₃) $\mu\text{g}/\text{m}^3$	Peak Season* 8-hour**	- 100	60 100
Nitrogen dioxide (NO ₂) $\mu\text{g}/\text{m}^3$	Annual 24-hour*	40 -	10 25
Sulfur dioxide (SO ₂) $\mu\text{g}/\text{m}^3$	24-hour	20	40
Carbon monoxide (CO) mg/m^3	24-hour*	-	4

WHO air quality guidelines from 2021
Source: <https://www.who.int/news-room/2021-who-air-quality-guidelines>

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Volatile organic compounds are mostly emitted by anthropogenic activities, such as the burning of fossil fuels in industrial processes, homes and motor vehicles.

The reactions that lead to O₃ formation are also heavily influenced by the meteorological fluctuations seen with climate change.

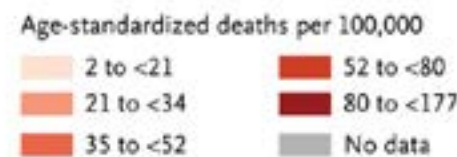
Increasing ambient temperature leads to increases in ground O₃ concentration that might be difficult to mitigate given the relationship between ambient temperature and O₃ levels. O₃ levels are measured as the 8-h maximum concentration in parts per million or billion by volume.

Evidence from a 2017 study suggests a continued relationship between O₃ levels and mortality at concentrations <60 parts per billion (ppb), which is a lower range than that considered by the US National Ambient Air Quality Standards (70 ppb over 8 h).

The effect estimates between O₃ levels and mortality are lower than that of PM2.5.

Epidemiology of air pollution and CVD: Cardiovascular mortality

A Global Cardiovascular Disease Mortality Attributable to Air Pollution



Source: from Rajaguru and Landrigan (2021)

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Numerous studies have highlighted the association between blood pressure and air pollution levels.

The prevalence of hypertension was linked to short-term and long-term exposure to $10 \mu\text{g}/\text{m}^3$ increments of $\text{PM}_{2.5}$.

Short-term exposure to increments of $10 \mu\text{g}/\text{m}^3$ in $\text{PM}_{2.5}$ has also been linked with 1–3 mmHg elevations in both systolic and diastolic blood pressure.

Personal strategies to limit air pollution exposure (such as the use of face masks and indoor air purifiers) were shown to significantly reduce blood pressure levels, thereby

supporting strategies to reduce air pollution as a way to prevent and treat hypertension.

A 2020 analysis showed a significant association between $10 \mu\text{g}/\text{m}^3$ increments in $\text{PM}_{2.5}$ levels and the incidence and prevalence of type 2 diabetes mellitus.

The investigators also found a significant association between $10 \mu\text{g}/\text{m}^3$ increments in NO_2 levels and the prevalence of type 2 diabetes.

Both short-term and long-term exposure to $\text{PM}_{2.5}$ and other pollutants increase the risk of cardiovascular events.

In a large US study ($n = 517,043$), long-term exposure (between 2000 and 2009) to $\text{PM}_{2.5}$

was linked to a 10% increase in cardiovascular mortality for every $10 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ levels.

Data from the 2001 Canadian Census Health and Environment Cohort showed that the 10-year hazard ratio estimates for cardiovascular mortality increased by 25% for every $10 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ concentration.

In a study from China, in the setting of high $\text{PM}_{2.5}$ levels (mean $43.7 \mu\text{g}/\text{m}^3$), every $10 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ levels was linked with a 12% increase in cardiovascular mortality.

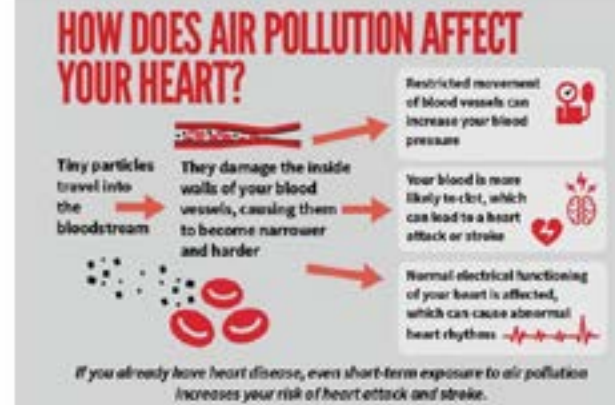
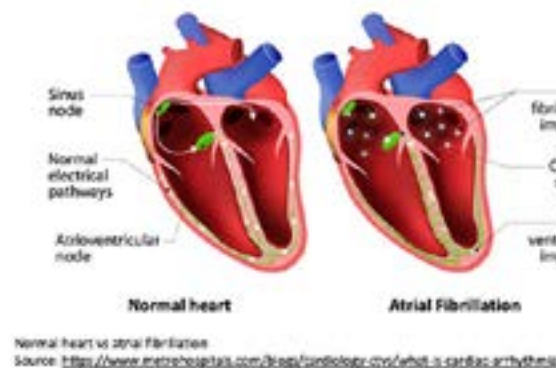
A meta-analysis of studies showed a modest but significant association between short-term exposure to $\text{PM}_{2.5}$ (24-h average concentration) and cardiovascular mortality.

A study of Meng et al. (2021) showed that a $10 \mu\text{g}/\text{m}^3$ increase in NO_2 exposure was associated with a 0.37% increase in cardiovascular mortality on the day after exposure.

The relationship between ground O_3 concentration and cardiovascular mortality remains unclear.

Epidemiology of air pollution and CVD

Cardiac arrhythmia



Source: <https://www.heart.org/press/health-care/press-releases/cvd-statistics-call-for-urgent-action-to-reduce-air-pollution>



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Short-term exposure to the main air pollutants (CO, NO₂, SO₂, PM₁₀ and PM_{2.5}, but not O₃) was associated with a marginal increase in the risk of Myocardial infarction (MI).

The investigators found increases of 1.1% and 2.5% in the risk of MI associated with each 10 µg/m³ increment in NO₂ and PM_{2.5} concentrations, respectively.

In an analysis of data from six population-based cohort studies from Denmark, Germany, Netherlands and Sweden (n = 137,148), 10 µg/m³ increments in long-term exposure to NO₂ was associated with a significant increase in the incidence of coronary artery disease (CAD). However, long-term exposure to ground O₃ or

PM_{2.5} was not associated with an increase in the incidence of CAD.

A meta-analysis of studies demonstrated that a 10 µg/m³ incremental increase in long-term exposure to PM_{2.5} was significantly associated with death from CAD, but not the incidence of MI.

Finally, the repetitive, continuous exposure to air pollution over a lifetime might contribute to the development of high-risk coronary plaques and amplify the risk of atherosclerosis.

Multiple studies have demonstrated a link between exposure to air pollution and heart failure (HF) hospitalizations.

The short-term exposure to the main air pollutants (CO, NO₂, SO₂, PM₁₀ and PM_{2.5}, but not O₃) was associated with an increase in HF hospitalizations and mortality.

The analysis also demonstrated that 10 µg/m³ incremental increases in PM_{2.5} levels were associated with a 2.12% increase in HF hospitalizations or death, with the strongest associations noted on the day of exposure.

A study of residents living in Ontario, Canada, also demonstrated a link between long-term exposure to major air pollutants and increased HF admissions

Increases of 5% and 3% in HF admissions were associated with each interquartile range increase in exposure to PM_{2.5} and O₃, respectively.

Further studies are warranted to confirm the relationship between long-term exposure to air pollution and HF risk.

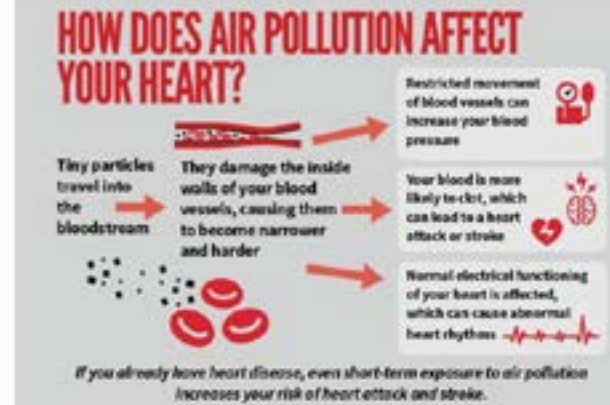
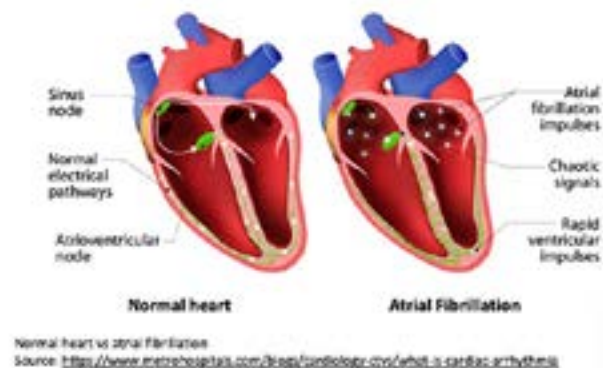
The link between short-term and long-term air pollution exposure and an increased risk of stroke is well established.

Positive association exists between short-term exposure to PM_{2.5} and stroke hospitalizations, incidence of stroke and stroke mortality. In addition, the analysis revealed a positive association between 10 µg/m³ increments in short-term exposure to NO₂ and stroke hospitalizations, stroke incidence and stroke mortality.



Epidemiology of air pollution and CVD

Cardiac arrhythmia



Source: <https://www.heart.org/press/health-care/coronary-artery-disease/call-for-action-to-reduce-air-pollution>



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A $10 \mu\text{g}/\text{m}^3$ increase in long-term exposure to $\text{PM}_{2.5}$ was linked with a 13% increased risk of incident stroke and a 24% increased risk of cerebrovascular death.

Moreover, a $10 \mu\text{g}/\text{m}^3$ increase in long-term exposure to NO_2 was associated with 8% increase in the incidence of stroke.

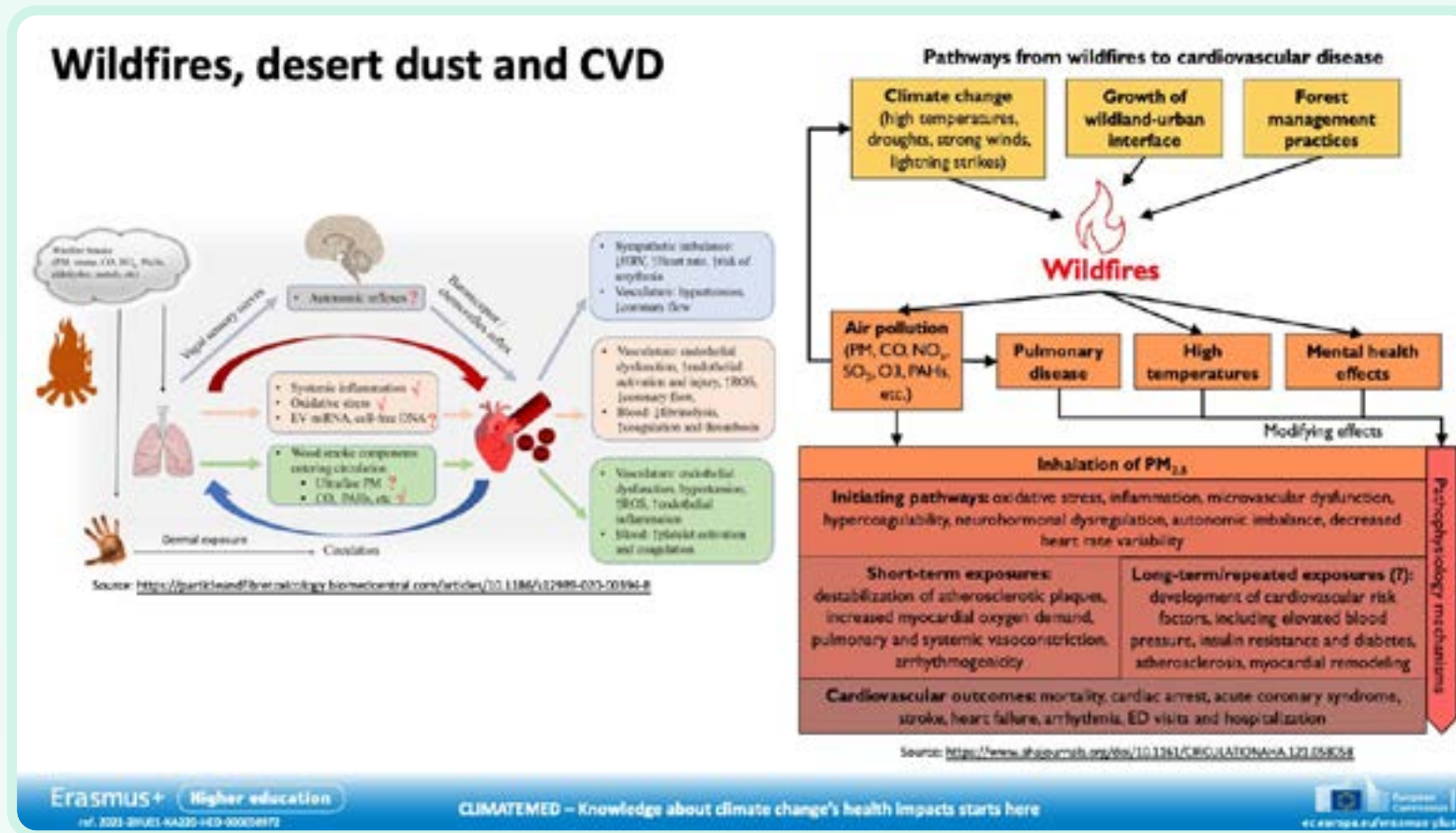
The associations between cerebrovascular events and exposure to PM_{10} or ground O_3 are less consistent.

Short-term exposure to air pollution has been shown to increase the risk of atrial fibrillation.

A $10 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ levels was associated with a 0.89% increase in the population-attributable risk of atrial fibrillation.

A study in patients with an implantable cardioverter-defibrillator found a 39% increased risk of a ventricular arrhythmia event with each interquartile range increase in $\text{PM}_{2.5}$ level.

Among healthy individuals and those with a history of CVD, both short-term and long-term exposure to $\text{PM}_{2.5}$ have been associated with an increased burden of premature ventricular contractions.



However, mixed results have been noted with cardiovascular hospitalizations.

For example, studies examining the communities affected by the forest fires in 2003 in British Columbia, Canada, and during the 1990s in Australia, found no increase in cardiovascular hospitalizations.

However, the studies that assessed the wildfires in 2003 in southern California, USA, and in 1997 in Indonesia, found higher cardiovascular hospitalization rates than in other years.

Given that forest fires are becoming an increasingly important contributor to air pollution, this source merits serious consideration as a risk factor for cardiovascular events.

Wildfire smoke, for example, might contain a substantial proportion of ultrafine particles, which are an emerging risk factor for CVD.

Furthermore, wildfire smoke might also contain oxidative components such as polycyclic aromatic hydrocarbons that can exacerbate the adverse cardiovascular effects.

In the immediate vicinity of wildfires, high temperatures and the release of other gaseous components might also exacerbate the adverse cardiovascular effects, particularly in individuals with pre-existing CVD.

Wildfire smoke is an increasingly important contributor to air pollution in many parts of the world.

Both the frequency and duration of wildfire events have dramatically increased in the past two decades as a consequence of climate change

Approximately 10.3 million individuals in the USA were estimated to have experienced unhealthy air quality levels (average daily fire-related PM_{2.5} >35 µg/m³) that were associated with exposure to wildfire for ≥10 days between 2008 and 2012.

Many studies have consistently demonstrated a link between short-term all-cause mortality

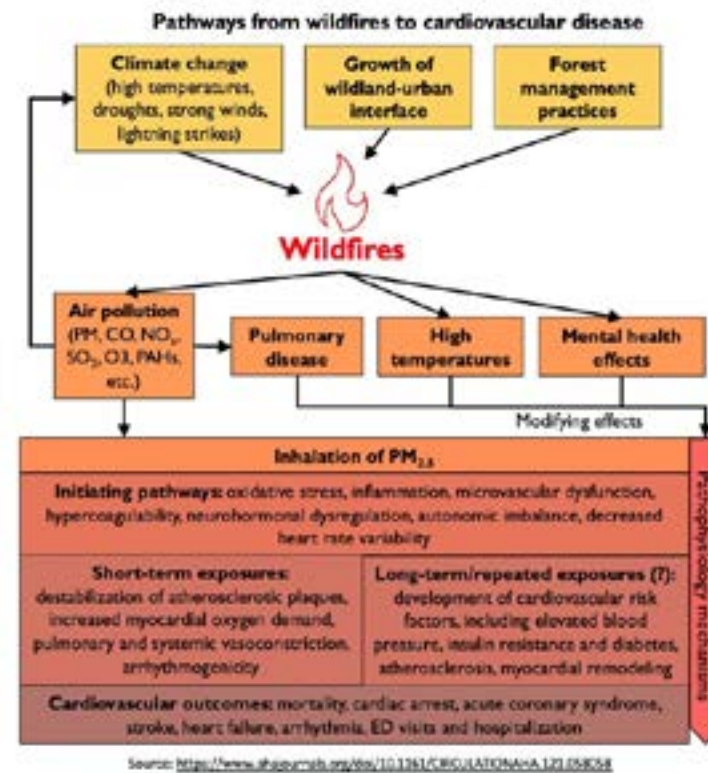
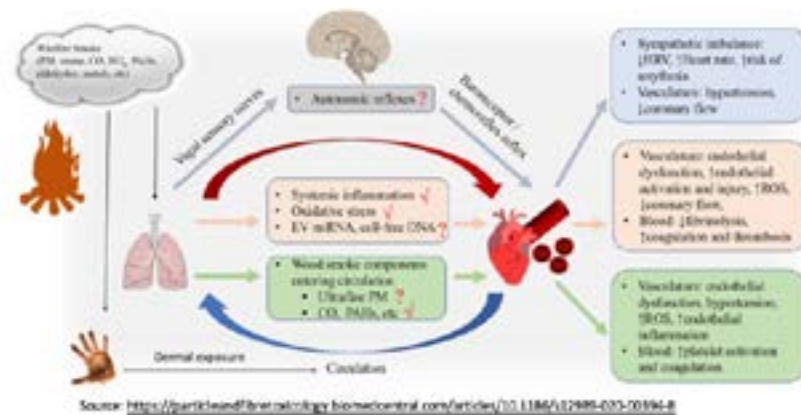
and wildfires, whereby each 10 µg/m³ increase in wildfire-related PM_{2.5} exposure resulted in a 0.8–2.4% increase in all-cause mortality.

Although the evidence linking wildfire smoke exposure to respiratory outcomes (including hospitalizations) is robust, the data on the relationship between wildfire smoke exposure and CVD are limited by the relatively smaller sample sizes.

PM_{2.5} exposure from wildfire smoke is associated with increased cardiovascular mortality and out-of-hospital cardiac arrests, with effect estimates similar to those mediated by ambient PM_{2.5} levels.



Wildfires, desert dust and CVD



In a study that examined the cardiovascular effects of dust that reached Taipei, Taiwan, from Asian desert storms, increases of 26%, 35% and 20% in emergency visits for overall CVD, ischaemic heart disease and cerebrovascular accidents, respectively, were observed during the storm-affected period compared with pre-storm periods

Given that sand and dust storms affect >150 countries worldwide, billions of individuals are at risk of the health consequences of these storms. Sand and dust storms are strongly related to climate change and a series of interlinked factors.

These factors include a warming climate, the El Niño phenomenon and larger differences in temperature between land and sea, resulting in larger pressure differentials that create strong winds, a reduction in rainfall, loss of soil moisture and deforestation.

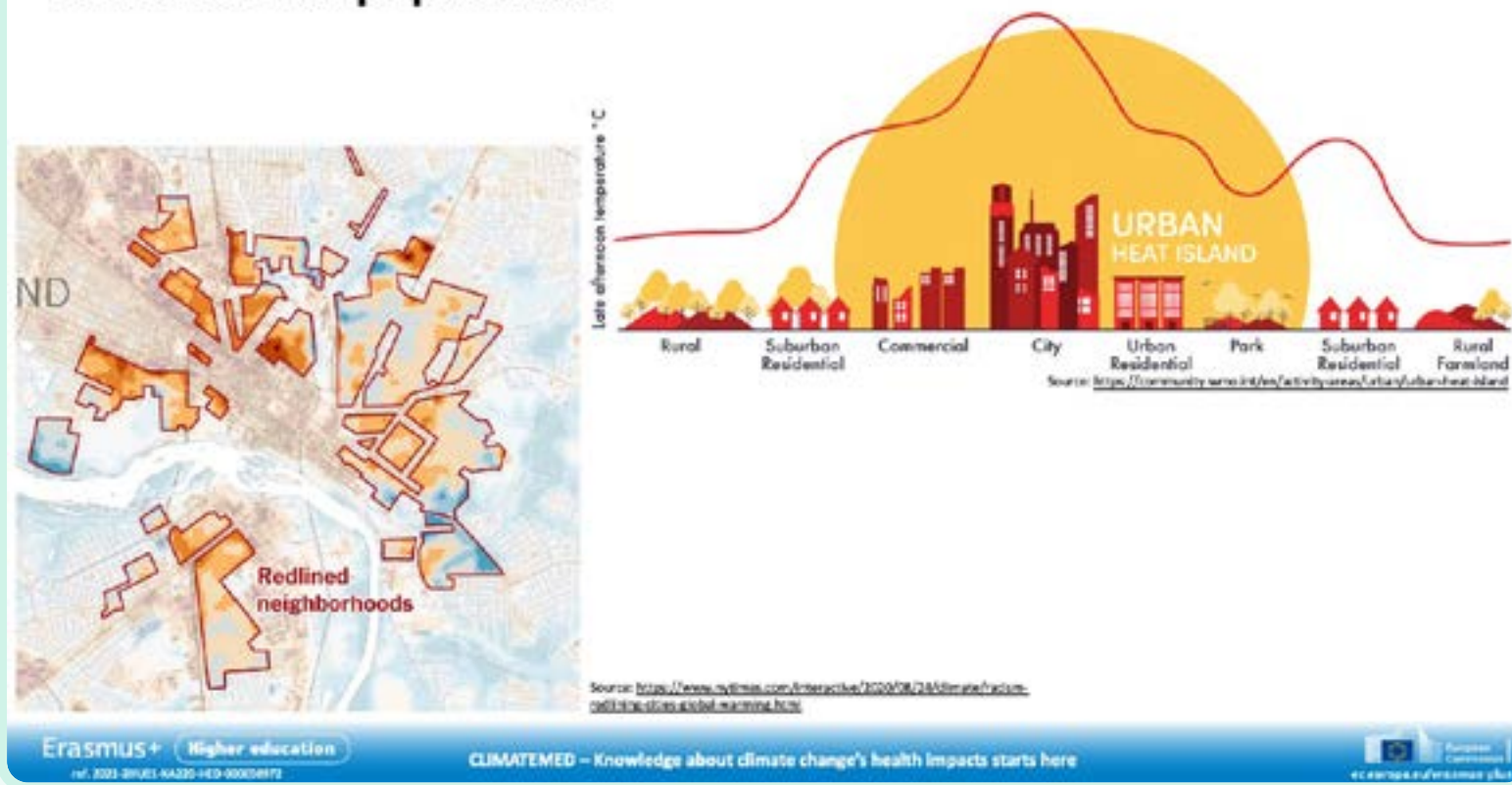
The main component of sand and dust storms is PM_{10} , but substantial amounts of coarse PM ($PM_{2.5-10}$) and $PM_{2.5}$ are also present.

The association between an increase in dust particle concentration and mortality suggests the likelihood of a short-term increase in mortality during dust storms.

Systematic review of the health effects associated with desert dust showed a 0.27% increase in all-cause mortality on dust days compared with non-dust days.

In a 2020 meta-analysis of studies on the health effects of dust exposure in Asia, a 2.33% increase in combined circulatory and respiratory mortality was observed during dust days compared with non-dust days on lag day 0 (the day of dust exposure) and a 3.99% increase on lag day 3 (3 days after the initial exposure).

Vulnerable subpopulations



Individuals from ethnic minority groups might also be more susceptible to the adverse health effects mediated by temperature-related events.

For example, African American individuals have an increased all-cause mortality during both heat-related and cold-related extreme weather events compared with white individuals, an effect that is driven by lower socioeconomic resources and numerous other socially disadvantageous circumstances among the African American population.

Climate change vulnerability is defined as the propensity to be adversely affected by climate change.

Coastal and low-lying geographical areas, as well as densely packed cities with poor infrastructural amenities, offer less protection from the potential health risks associated with extreme climate change-related events

Other factors such as homelessness, type of housing and lack of green spaces contribute to climate change vulnerability.

For example, during the heatwave in the summer months of 2003 in Europe, residents in old buildings with a lack of thermal insulation

had a twofold increased risk of death compared with residents living in well-insulated buildings.

Climate change has differential effect across various demographic and socioeconomic subgroups living in different geographical areas.

Age is the most consistent individual-level effect modifier of temperature-related cardiovascular mortality, with older individuals being more vulnerable to the adverse health effects mediated by temperature extremes.

During the heatwaves in 1995 in Chicago, USA, and in 2003 in Paris, France, mortality was the highest in bed-bound, older patients with comorbidities, such as obesity, CVD, and mental and neurological disorders.

Vulnerable subpopulations



Source: <https://www.time.com/2014/06/02/thousands-of-migrant-workers-died-in-qatar-extreme-heat/>

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health training and high risk of occupational injuries

Compromised mobility, reduced cognitive function, and other mental or behavioural factors might also increase susceptibility to climate-related health effects, particularly if no action is taken to mitigate these risks.

An individual's job can also affect the individual's susceptibility to climate-related health effects.

Manual and construction workers tend to work outdoors and are exposed to heat and pollution.

During the 2003 heatwaves in Paris, France, manual workers had a twofold to threefold higher all-cause mortality compared with individuals with an office job.

In hot regions, migrant workers take on more demanding work and therefore have substantial outdoor exposure to extreme heat and air pollution.

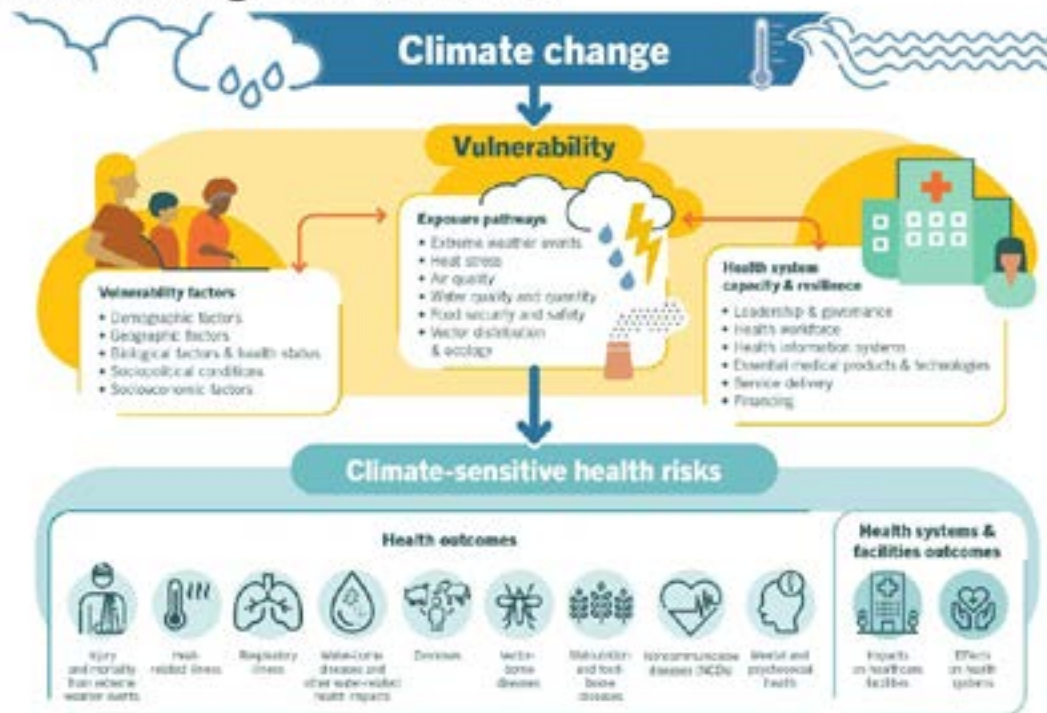
→ In Kuwait, a threefold higher risk of cardiovascular death from extreme heat among migrant workers was found compared with the host population.

Refugees and immigrants are another subpopulation at increased risk of climate-related cardiovascular events.

Language barriers, poor living conditions and socioeconomic disparities have been linked with increased heat-related vulnerability in refugees.

Migrant workers tend to take jobs with less pay and longer hours, are often unprotected by public policies, and work under unsafe conditions with little occupational safety and

How to mitigate climate change-related CVD?



Source: <https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health>

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Climate change highlights the dilemma that medical professionals confront in addressing individual-level health problems that manifest from larger hierarchical and cross-systemic processes.

Therefore, untargeted strategies or recommendations for personal-level intervention are unlikely to be the most effective approach from a cost, effort or equity standpoint.

A multilevel intervention from an individual-level to a system or worldwide approach is urgently needed to address this existential problem.

This intervention should involve cross-disciplinary collaboration between physicians, researchers, public health workers, political scientists, legislators and national leaders to mitigate the effects of climate change.

The threats brought about through climate change propelled 190 countries to agree to the provisions of the Paris Agreement signed in 2015.

Under the agreement, countries would limit global warming to <2.0 °C above preindustrial levels (with a more ambitious target of <1.5 °C).

The agreement further recognized the important role of sub-state actors such as local and regional authorities, civil society and

the private sector in adapting to the different condition that might affect regions, countries and local environments with climate change.

A multiregional analysis that included 451 locations in 23 countries evaluated heat-related and cold-related mortality under scenarios consistent with the Paris Agreement targets (1.5 °C and 2.0 °C increases) versus more extreme scenarios (3.0 °C and 4.0 °C increases).

If global mean temperatures stay within the targets of the Paris Agreement, the analysis predicted that large increases in temperature-related mortality will be prevented.

An assessment of patient-specific and community health risk and the degree of climate-related exposures is important for the implementation of any mitigation strategy.

A key focus of this strategy is climate adaptation that focuses on preparing for, coping with and responding to the effects of current and subsequent climate change problems.

The strategy is centrally focused on managing risks and uncertainties posed by climate change.

Therefore, the adaptation process is particularly important to cardiovascular health given the variable effect that climate change will have at all levels, from individuals to communities, countries and regions.

One clear area of focus is on climate-resilient buildings and infrastructure.

How to mitigate climate change-related CVD?



Source: <https://www.who.int/news-room/fact-sheets/detail/heat-related-health>



Source: <https://www.who.int/news-room/fact-sheets/detail/heat-related-health>

appropriate preventive measures and to improve HHAPs.

Climate-resilient infrastructure is defined as a planned, designed, built and operated approach that anticipates, prepares for and adapts to substantial environmental stressors.

This infrastructure should be designed and constructed to withstand, respond to and rapidly recover from disruptions caused by climate extremes, especially for vulnerable individuals with pre-existing CVDs.

Healthy buildings should promote thermal comfort and have the potential to prevent adverse health outcomes.

Individual-level climate change adaptation includes installation of air conditioning and heating systems and air purifiers.

Heat-health action plans (HHAPs) are an example of a framework that was developed by the WHO regional office for Europe in response to the 2003 summer heatwaves and were adopted by several regional and subnational authorities to direct their heat-prevention efforts.

HHAPs include guidance for a collaborative response to excessive heat conditions, timely alert systems, information dissemination, reduction in indoor heat exposure, emergency response of health-care systems and urban planning.

To date, the data on the effectiveness of HHAPs are limited and further studies are needed to assist decision-makers to select the most

Take-home messages for physicians and cardiologists



Source: <https://www.jacc.org/doi/10.1016/j.jacc.2022.10.040>

- Climate change, environmental exposures and occupational history should be considered major risk factors that can negatively affect cardiovascular and general health.
- Physicians should be able to provide **guidance on how to mitigate these risk factors**, particularly for patients with multiple cardiovascular risk factors or a history of cardiovascular disease.
- These recommendations can be divided into two broad categories that **mitigate air pollution or extreme temperatures** induced by climate change.

Take-home messages for physicians and cardiologists

Examples of **recommendations to reduce air pollution exposure** include:

- avoiding outdoor exercise activity on days with elevated pollution levels,
- use of N95 or fine particulate matter (PM_{2.5}) masks,
- use of indoor air purifiers, and
- installation of heating, ventilation and air conditioning units with a high-efficiency particulate air filter
- vulnerable patients should also avoid using gas stoves, fireplaces and incense, which can all exacerbate indoor air pollution.



Take-home messages for physicians and cardiologists



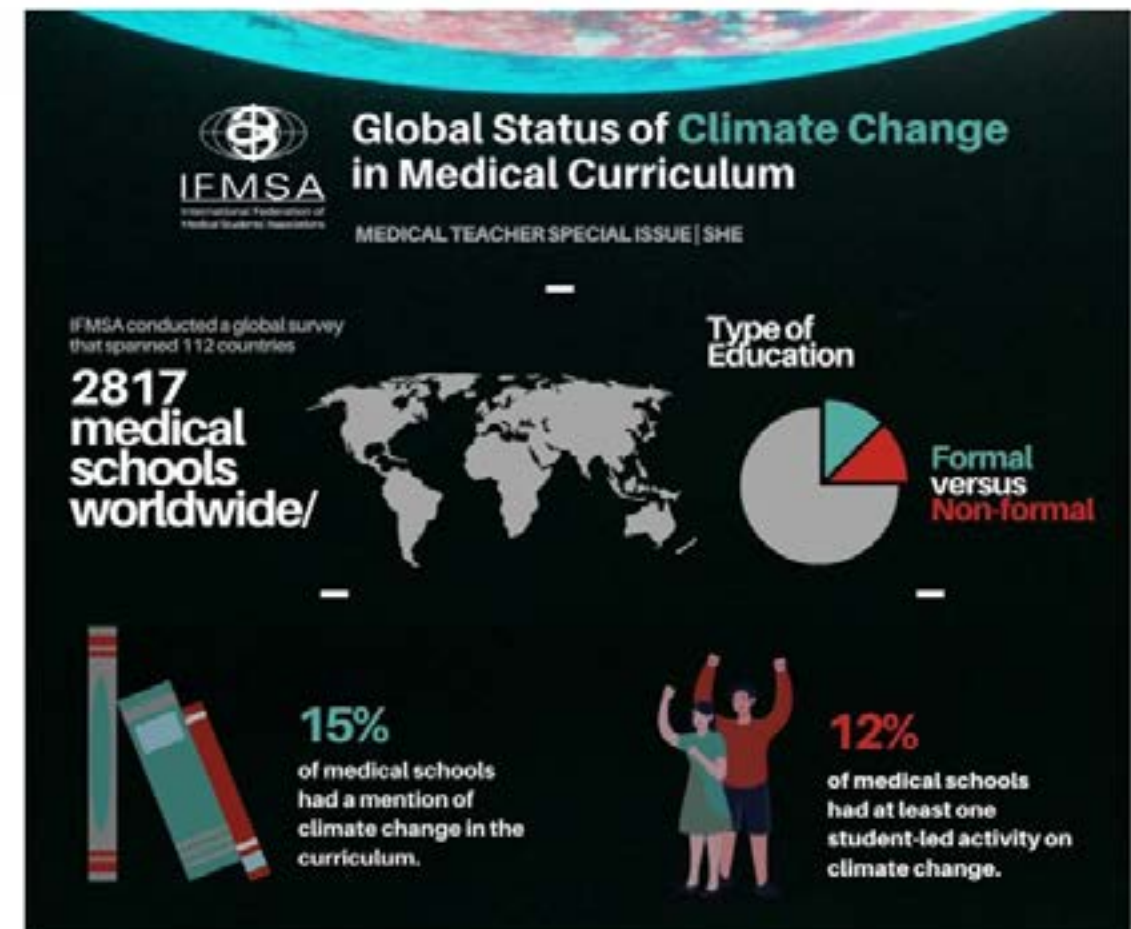
Source: <https://www.weather.gov/rah/heat>

To mitigate heat risks, patients should be counselled on

- avoiding outdoor activities during days with extreme heat conditions,
- on maintaining proper hydration, and
- on how to utilize indoor thermal control systems and reduce reliance on traditional air conditioning units that can themselves be contributors to greenhouse gas emissions.

Take-home messages for physicians and cardiologists

- The wider medical community must also engage in the conversation and debate on **climate change**, which begins fundamentally with **training in medical school**.
- **Physicians must be conveyors of climate information** during medical training, but also beyond medical school in policy forums.
- Calls have been made to **integrate climate change and its effects on health in curricula** across the spectrum of medical education.
- A framework that includes how climate change can harm health, necessitate adaptation in clinical practice and undermine health-care delivery should be adopted by the accreditation Council for Graduate Medical education in the USA, and by relevant councils in other countries, as core competencies for resident education.



Source: <https://twitter.com/IFMSA/status/1310634998748385283/photo/1>

Take-home messages for physicians and cardiologists

- The medical community, especially **cardiologists** must engage in the **policy conversation**.
- A multinational survey of **health professionals** showed a **consistent understanding of the health damage of climate change** in their countries and found that they felt a responsibility to educate the public and policymakers about the problem.
- Despite this finding, **less than half of the general public are personally concerned about the health effects of climate change**.
- These assessments are fed by a **misperception** that climate change does not affect everyone.
- **Health-care professionals must be a conduit of education and information** that emphasizes the individual consequences of the long-term detrimental effects that climate change can have on all people.



Source: <https://grist.org/health/doctors-climate-change-health-medicine-anthony-fauci/>

KEY MESSAGES

- The climate change and CVD crises are interconnected health issues
- The significant climate change impact factors on CVD are due to changes in the intensity, duration and frequency of extreme air temperature events, air pollution, wildfires, desert dust, etc.
- Climate-change related CVD should be mitigated by interventions that involve cross-disciplinary collaboration between physicians, researchers, public health workers, political scientists, legislators and national leaders
- Key vulnerable population are the elderly, outdoor workers, ethnic minority groups, pregnant women and children living in poor socioeconomic conditions
- Physicians and wider medical community must be conveyors of climate information during medical training and practice

Suggested readings

- 1) Khraishah, H., Alahmad, B., Ostergard, R.L., AlAshqar, A., Albaghdadi, M., Vellanki, N., Chowdhury, M.M., Al-Kindi, S.G., Zanobetti, A., Gasparrini, A. and Rajagopalan, S., 2022. Climate change and cardiovascular disease: implications for global health. *Nature Reviews Cardiology*, pp.1-15.
- 2) Khraishah H, Ganatra S, Al-Kindi S, et al. Climate Change, Environmental Pollution, and the Role of Cardiologists of the Future. *J Am Coll Cardiol*. 2023 Mar, 81 (11) 1127–1132.
- 3) Roth, G.A., Mensah, G.A., Johnson, C.O., Addolorato, G., Ammirati, E., Baddour, L.M., Barengo, N.C., Beaton, A.Z., Benjamin, E.J., Benziger, C.P. and Bonny, A., 2020. Global burden of cardiovascular diseases and risk factors, 1990–2019: update from the GBD 2019 study. *Journal of the American College of Cardiology*, 76 (25), pp. 2982-3021

TEST YOUR KNOWLEDGE

- 1) Which climate change factors can exacerbate disease in individuals with CVD conditions? Mention at least three factors.
- 2) How does changes in air temperature impact CVD?
- 3) How does air pollution impact CVD?
- 4) Which are the vulnerable subpopulations to the impacts of climate change on CVD?
- 5) How to mitigate climate change related CVD impacts? Mention at least three examples.
- 6) How can physicians incorporate climate change knowledge in their medical practice?

Thank you for you attention!

This presentation has been developed by the CLIMATEMED project, supported by EU's Erasmus+ programme.



University of Pécs Medical School – Pécs, Hungary



Center for Health, Exercise and Sport Science – Novi Sad, Serbia



National Public Health Center – Budapest, Hungary



University College Cork – National University of Ireland – Cork, Ireland



Universitatea de Medicina, Farmacie, Stinte si Tehnologie
George Emil Palade din Tirgu Mures – Tirgu Mures Romania

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Climate change and metabolic disorders

Learning outcomes

Upon successful completion of the lesson, students will be able to:

- Describe the interconnections between accelerating global emergency: climate change and epidemic of T2D/obesity
- Understand epidemiological observations with evidence-based explanations about heat exposure in T2D/obesity
- Identify populations that are particularly vulnerable to climate change-related effects on metabolic health
- Understand potential biological mechanisms behind extreme heat/cold/air pollution exposure and metabolic dysfunction
- Recognize how climate change may interact with other environmental changes and their separated/combined impacts on patient with metabolic disorders
- Discuss how mitigation of climate change in various sectors including urbanisation, transportation and food system can lead to health co-benefits and reduced health risks
- Identify actions health professionals can take to prepare populations with compromised metabolic health for extreme weather events and natural disasters

Climate change impacts and risks



Fact sheet - Europe

Climate Change Impacts and Risks



Climate change impacts and risks

Our current 1.1°C warmer world is already affecting natural and human systems in Europe (very high confidence). Impacts of compound hazards of warming and precipitation have become more frequent (medium confidence). Largely negative impacts are projected for southern regions. (ES-Ch13)



Key Risks

Four key risks have been identified for Europe, with most becoming more severe at 2°C global warming levels (GWL) compared with 1.5°C GWL in scenarios with low to medium adaptation (high confidence). From 3°C GWL and even with high adaptation, severe risks remain for many sectors in Europe (high confidence). (ES-Ch13)



Key Risk 1: Mortality and morbidity of people and changes in ecosystems due to heat

The number of deaths and people at risk of heat stress will increase two- to threefold at 3°C compared with 1.5°C GWL (high confidence). Above 3°C GWL, there are limits to the adaptation potential of people and existing health systems (high confidence). (ES-Ch13; 13.7.1)

Warming will decrease suitable habitat space for current terrestrial and marine ecosystems and irreversibly change their composition, increasing in severity above 2°C GWL (very high confidence). Fire-prone areas are projected to expand across Europe, threatening biodiversity and carbon sinks (medium confidence). (ES-Ch13)



Key Risk 2: Heat and drought stress on crops

Substantive agricultural production losses are projected for most European areas over the 21st century, which will not be offset by gains in Northern Europe (high confidence). While irrigation is an effective adaptation option for agriculture, the ability to adapt using irrigation will be increasingly limited by water availability, especially in response to GWL above 3°C (high confidence). (ES-Ch13)



Key Risk 3: Water scarcity

In Southern Europe, more than a third of the population will be exposed to water scarcity at 2°C GWL; under 3°C GWL, this risk will double, and significant economic losses in water- and energy-dependent sectors may arise (medium confidence). For Western Central and Southern Europe, and for many cities, the risk of water scarcity will increase strongly under 3°C GWL. (ES-Ch13)



Key Risk 4: Flooding and sea level rise

Above 3°C GWL, damage costs and people affected by precipitation and river flooding may double. Coastal flood damage is projected to increase at least tenfold by the end of the 21st century, and even more or earlier with current adaptation and mitigation (high confidence). Sea level rise represents an existential threat for coastal communities and their cultural heritage, particularly beyond 2100. (ES-Ch13)

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European people's health is impacted by climate change (CC) in a countless of ways

Key risk 1 is an increase in heat-related mortality and morbidity of people and changes in ecosystems due to heat.

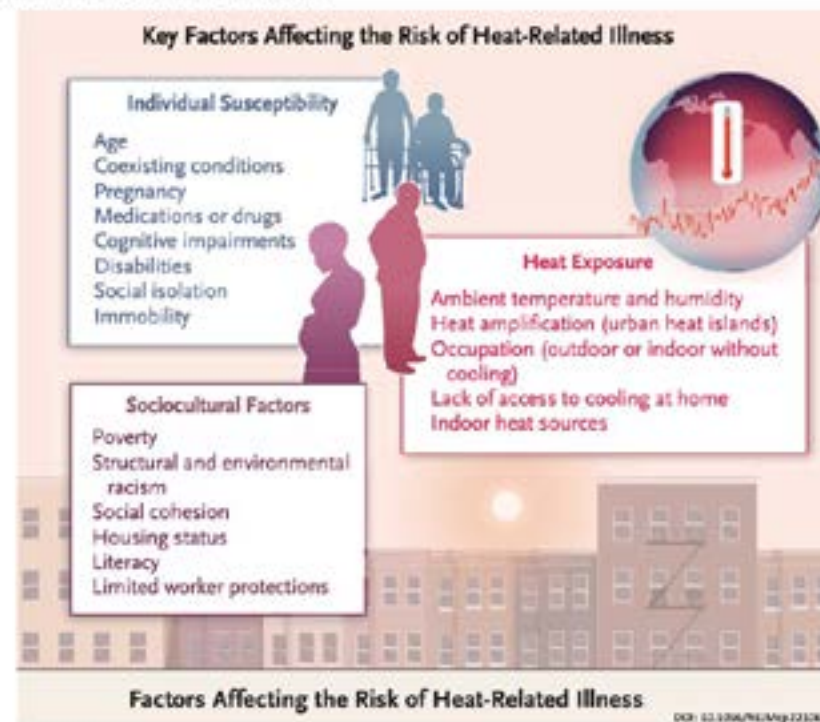
Other significant CC drivers are natural disaster as consequence of extreme heat, including droughts, bushfires and flooding.

As frequency of heatwaves rises, water availability and crop yield drop, fire danger and exposure increase and sea level rise.

Who is at greatest risk for heat-related illness?

CC impacts and risks of heat-related illness

Metabolic disorders
as the modifiable factor



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CLIMATEMED

Among numerous factors that modify the risk of heat-related illness are coexisting conditions

Diabetes and obesity (**metabolic disorders**) are common comorbidities for heat-related illness

The prevalence of metabolic disorders has increased in recent decades around the world and represents a major public health burden.

Diabetes mellitus (diabetes) is a group of metabolic disorders of carbohydrate metabolism characterized by high blood glucose levels (hyperglycemia) and usually resulting from, insufficient production of the hormone insulin (type 1 diabetes), an ineffective response of cells to insulin (type 2 diabetes),

and developing high blood glucose level during pregnancy (gestational diabetes).

Type 2 diabetes (T2D) is the most common metabolic disorder, and obesity is the most important risk factor for T2D.

Obesity is a chronic metabolic disorder, that is defined as excessive fat accumulation and presents a risk to health (BMI > 30). Obesity is of high concern because it is the main risk factor for a number of NCDs such as CVD, some types of cancers and T2D.

Almost 90% of persons suffering from type 2 diabetes are obese. An individual with obesity is approximately 10 times more likely to develop

type 2 diabetes than someone with a moderate body weight.

Obesity and diabetes have reached epidemic proportions and continue to progress worldwide.

Metabolic syndrome (MetS) is a cluster of conditions that occur together, increasing your risk of heart disease, stroke and T2D. These conditions include increased blood pressure, high blood sugar, excess body fat around the waist, and abnormal cholesterol or triglyceride levels.

MetS is close associated with the global epidemic of obesity and T2D.

*** Important note:** We are not going to elaborate on Mets separately, except impairment of lipid metabolism

Current estimates and future trends in chronic metabolic disorders that interact with the health risks associated with climate change (CC)

Health Conditions	Current Estimates	Future Trends	Possible impact of CC
Diabetes	<u>In 2021</u> , 537 million adults globally were living with diabetes; almost 1 in 2 (240 million) adults were living with diabetes are undiagnosed; more than 1.2 million children and adolescents were living with T1D; 1 in 6 live births (21 million) were affected by diabetes during pregnancy; 541 million adults were at increased risk of developing T2D	The total number of people living with diabetes is projected to rise to 643 million by 2030 and 783 million by 2045 .	For every degree Celsius rising in global temperature the diabetes incidence increases by 0.31%; diabetes increases sensitivity to heat stress/ heighten the risk (reach of 56%) for hospitalisation and the risk of morbidity at extremely high temperatures or during exposure to heatwaves; the elderly with autonomic neuropathy complications are at a higher risk of developing hypothermia in cold environments ; diabetes increases the negative cardiovascular effects of air pollution .

<https://idf.org/aboutdiabetes/what-is-diabetes/facts-figures.html>, accessed 6 February 2023

DOI 10.1088/1755-1315/1016/1/012054

DOI: 10.1016/j.diabet.2020.10.003.

Current estimates and future trends in chronic metabolic disorders that interact with the health risks associated with climate change (CC)

Health Conditions	Current Estimates	Future Trends	Possible impact of CC
Obesity	The worldwide prevalence of obesity nearly tripled between 1975 and 2016 <u>in 2016</u> , there were around 2 billion adults overweight , of those 650 million were obese ; 41 million children under 5 years were overweight or obese ; more than 124 million children and adolescents aged 5-19 were obese .	If current trends continue, it is estimated that 2.7 billion adults will be overweight; over 1 billion affected by obesity; and 177 million adults severely affected by obesity by 2025.	Obesity increases sensitivity to heat stress and risk of heat-related illness or injury/ obese older adults are more likely to die during the heatwave; heatstroke occurs much more frequently in obese or overweight people; elevated air pollution with ambient PM 2.5 is linked to reduced physical activity and consequently increasing rate of obesity.
MetS	The prevalence of MetS is 20-30% of the adults most countries worldwide. <u>In 2020</u> , about 3% of children (around 25.8 million) and 5% of adolescents (around 35.5 million) had MetS	MetS will be on the rise in the future, considering current trends of it's components.	Components of MetS increase sensitivity to heat stress and risk of heat-related illness or injury ; exposure to air pollutants can potentially increase the risk for dyslipidemia and development of the MetS .

<https://www.worldobesity.org/about/about-obesity/prevalence-of-obesity> accessed 6 February 2023

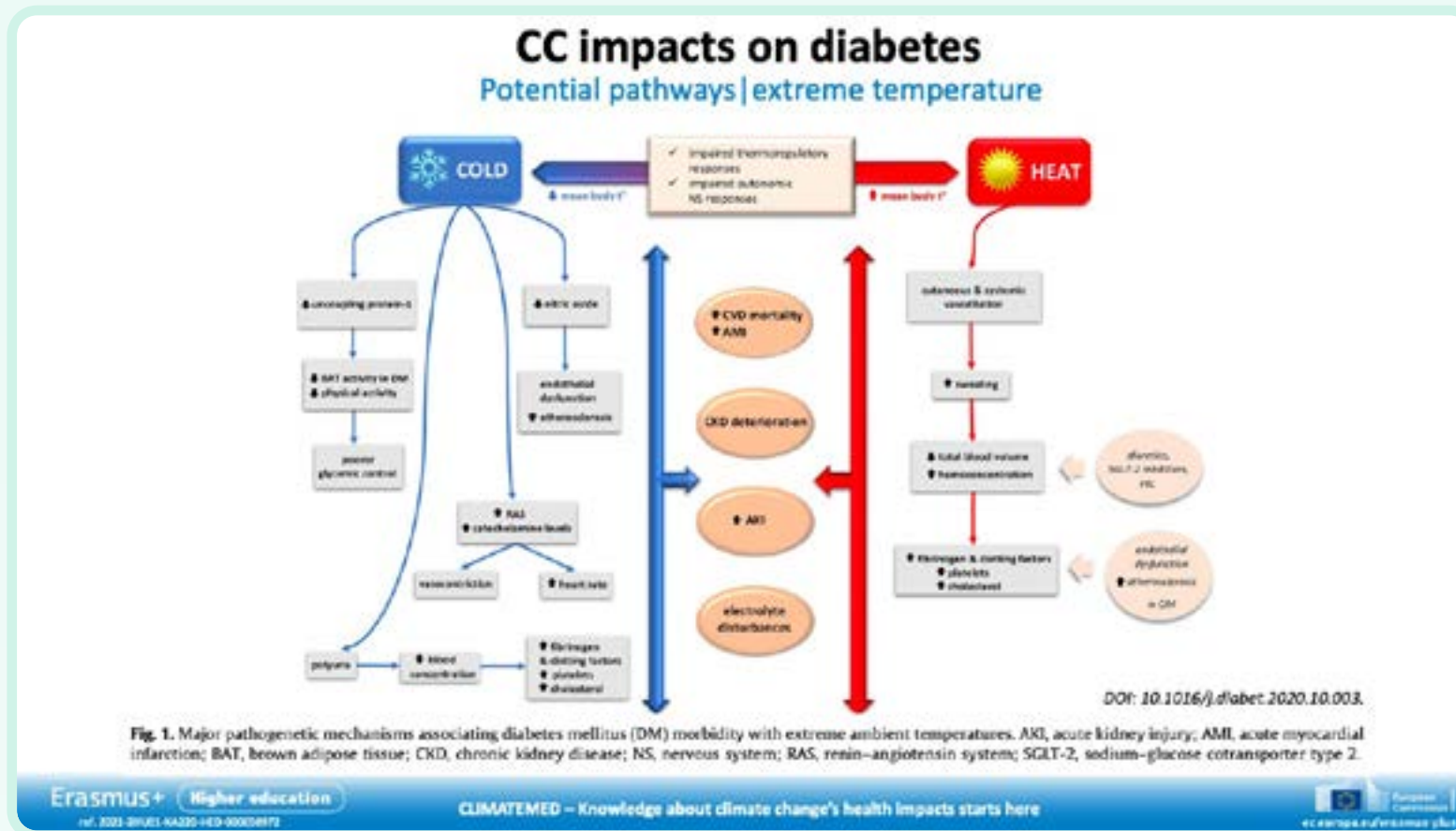
DOI:10.1503/cmaj.081050.

DOI:10.1371/journal.pmed.1003767.

DOI: 10.1016/S2352-4642(21)00374-6.

DOI: 10.1007/s13167-022-00273-6.

DOI: 10.5772/39004.



threatening exacerbations of disease: abnormalities of the thermoregulatory capacity, effects on glucose tolerance and dehydration predisposes T1D patients to diabetic ketoacidosis (DKA) state and T2D patients to hyperosmolar hyperglycemic (HHS) state.

- Prolonged heat exposure → dehydration → hyperthermia
- Increased insulin absorption → hypoglycemia
- Hyperglycemia → exaggerated dehydration → cardiovascular (CV) events, acute kidney injury (AKI)
- Polypharmacy → exaggerated renal impairment → AKI

→ doi: 10.1016/j.envres.2021.110762.

→ doi: 10.1016/j.diabet.2020.10.003.

The magnitude of the global diabetes burden is large and on the rise, according to the GBD 2015 study.

Mortality from diabetes and chronic kidney diseases due to diabetes increased worldwide at a rate more than 10-fold greater than cardiovascular diseases and almost 4-fold faster than cancers.

Could it be due to climate change?

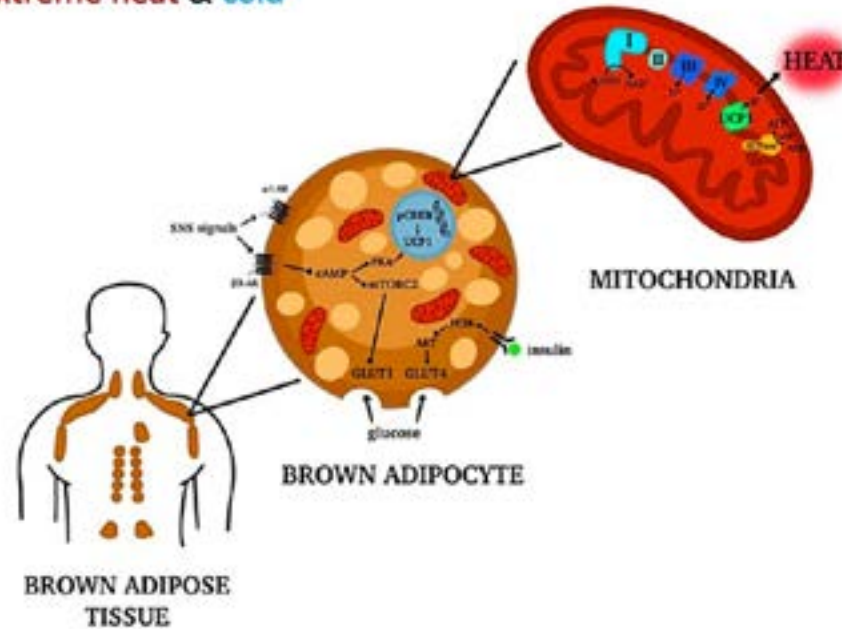
→ doi: 10.1093/advances/nmz035.

→ Exposure to extreme heat exacerbate diabetes-related dysfunctions (cardiovascular, metabolic, and neurological): impair thermoregulatory response, reduce capacity to dissipate heat and/or increase the risk of heat stress and hyperthermia.

- Microvascular complications → reduce skin blood flow → decrease vasodilatation ability → reduce capacity for dry heat exchange
- Peripheral neuropathy and autonomic dysfunction, poor glycemic control → disrupt the sweating response → reduce capacity for evaporative heat loss
- Prolonged exposure to extreme heat or heatwave increase the risk for life-

CC impacts on diabetes risk

Potential pathways | extreme heat & cold



More hospitalization due to hypothermia, particularly elderly women with diabetes.

Possible pathways of extreme cold impact are:

Increasing risk for hypoglycemic complications

Worsening of glycemic control → increase frequency of CVD symptoms (e.g. chest pain, arrhythmias, cough and dyspnea)

Diabetic autonomic dysfunction, reduced production of nitric oxide as signaling molecule → impaired vasoconstriction ability, increase heat loss → hypothermia

Peripheral neuropathy → sensory and thermoregulatory dysfunction, especially in the extremities

Reduced BAT mass and its activity impair the ability to generate heat in colder temperatures

Brown Adipose Tissue (BAT) distribution in adult human body. In adult humans of BAT depots are located mainly in the supraclavicular, paravertebral, axillar, cervical and per-aortic areas.

The tissue is formed by brown adipocytes, characterized by multiple lipid droplets and the expression of high levels of uncoupling protein 1 (UCP1) on the inner mitochondrial membrane. UCP1 is responsible for the release of energy in the form of heat, generating the process called non-shivering thermogenesis.

Moreover, the brown adipocytes activation contributes to systemic clearance of glucose and lipids.

doi: 10.3390/nu13051450

Rising global temperature possibly contribute to the diabetes epidemic, as diabetes incidence and glucose intolerance prevalence increase with higher ambient temperature.

Possible mechanism: higher environmental temperatures negatively affect glucose metabolism through a reduction in the brown adipose tissue (BAT) activity.

Therapies targeting BAT thermogenesis are increasingly recognized as therapies for obesity and diabetes.

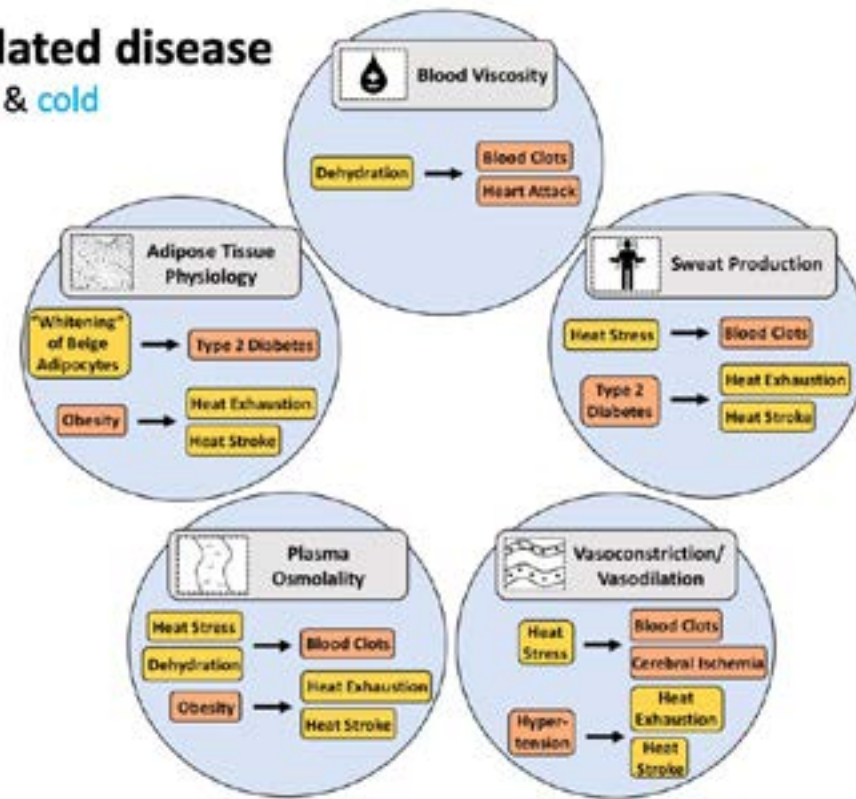
Extreme cold exposure contribute to the higher risk for morbidity and mortality in diabetes patients.

→ DOI: 10.1016/j.diabet.2020.10.003

→ doi: 10.1136/bmjdr-2016-000317

CC impacts on obesity-related disease

Potential pathways | extreme heat & cold



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Overweight and obese adults suffer fatal heatstroke 3.5 times more frequently than individuals of average body weight.

The biological pathways responsible for adaptation to heat stress overlap with those involved in the etiology of obesity-related cardiometabolic disease.

Biological pathways involved in the etiology of both obesity-related diseases and morbidities. The figure highlights five biological mechanisms (large blue circles) through which health-related conditions (in yellow) and cardiometabolic disease (in red) interact.

Possible mechanisms for increased risk of heat stress associated with obesity:

- Reduced capacity for heat dissipation due to morphological configuration affecting heat loss:
- Higher body mass-to-surface area ratio
- Higher subcutaneous fat, that have lower thermal conductivity
- Higher prevalence of dehydration
- Sensory impairment to heat
- Impaired skin blood flow in response to elevated core temperature

Cold weather exposure contribute to the higher prevalence of obesity

Possible pathways of ambient cold impact are:

influencing the hormones that are related to the hunger and appetite and impacts overall metabolite rates

increasing the energy expenditures or energy intakes that caused to an increased appetite toward overeating to preserved the body energy level

enhancing the desire of consuming more sweet foods that could significantly affect weight gain is short-term

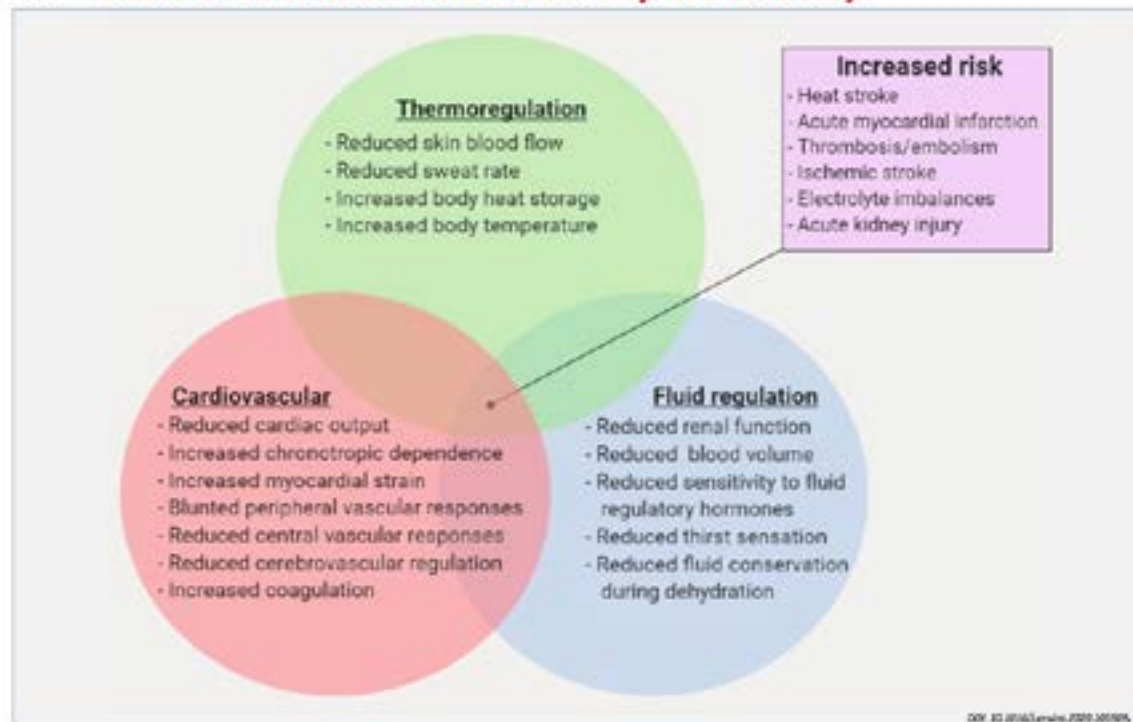
causing kind of sedentary lifestyle, staying in cozy and warmer environment rather than being outside and to stay more active

→ doi: 10.1503/cmaj.081050.

→ doi: 10.1002/ajhb.23460.

→ doi: 10.1002/ajhb.23460

CASE STUDY - Extreme heat vulnerability in elderly



SGLT2 inhibitors, that make them particularly prone dehydration.

→ doi: 10.1002/ajhb.23460.

→ DOI: 10.1016/j.envint.2020.105909.

→ DOI: 10.1016/j.cger.2014.08.017.

→ DOI: 10.1016/j.diabet.2020.10.003.

Older adults are particularly vulnerable to heat exposure, especially those with common age-associated chronic health conditions (e.g., CV disease, hypertension, obesity, T2D, chronic kidney disease).

- Obese older adults were twice as likely to die during the 2003 European heatwave
- The older adults with T2D stored 1.5-times more heat due to diabetes-related impairments in heat loss.

The ability to effectively acclimatize to heat stress declines with age due to: thermoregulatory, cardiovascular and fluid regulatory systems.

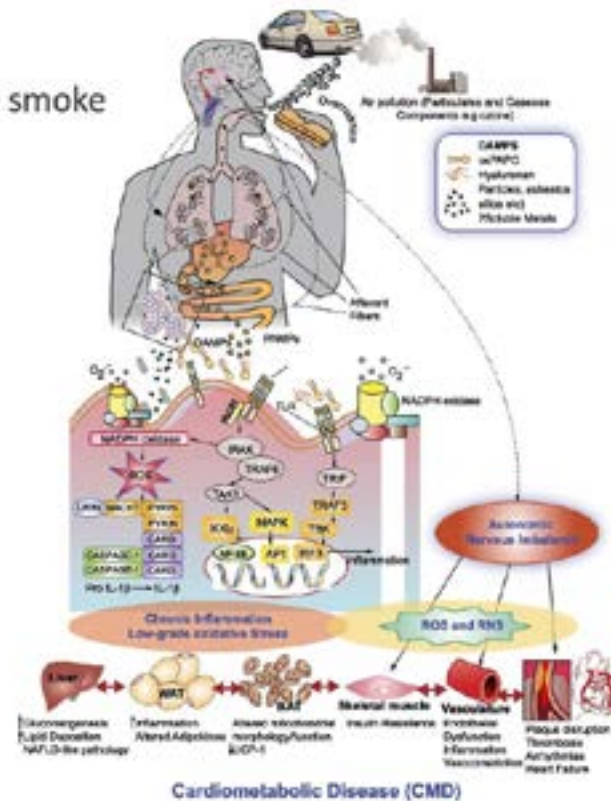
Medications are an important risk factor for increased vulnerability in older adults. Multiple comorbidities in elderly resulting in the consumption of multiple medications concomitantly (polypharmacy).

- Management of hyperglycemia, microvascular and macrovascular complications, geriatric syndromes associated with diabetes and potentially serious adverse effects of antidiabetic medications, contribute to polypharmacy among older adults with diabetes.
- Beside antidiabetic medication, they usually take other drugs (e.g., salicylates and antipsychotics) that may affect their thermoregulation capacity, and diuretics and

CC impacts on metabolic disorders

Potential pathways | ambient air pollution and bushfire smoke

Hypothesized mechanisms of air pollution-mediated cardiometabolic disease wherein inhalational or nutritional signals either directly or via the generation of signals such as DAMPs may serve to activate innate immune mechanisms such as the TLR and NLR.



DOI: 10.1371/journal.pone.0207767
DOI: 10.1371/journal.pone.0207767

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Two of these urgent challenges in the 21st century are the global diabetes epidemic and CC.

Diabetes and CC are directly and indirectly interconnected.

Direct connections refer to how diabetes and CC adversely impact upon each other.

Indirect connections refer to the common global vectors and pathways that encouraging both these health and development disasters.

Possible mechanisms: increased oxidative stress, triggered adipose tissue inflammation, induced BAT dysfunction and insulin resistance, increased blood lipid level and risk of hypertension.

Other possible mechanisms are the disturbed autonomic nervous system, epigenetic changes, mitochondrial dysfunction, as well as alterations in the composition and function of the human gut microbiome.

Exposure to particulate matter (PM) is the major public health concern. PM comprises organic and inorganic solid and liquid particles suspended in the air, where sulphates, nitrates, ammonia, sodium chloride, black carbon and mineral dust are all related to both short- and long-term adverse health effects.

According to one study, the prevalence of diabetes is 77.5% higher among people living in areas of high PM exposure compared to people living in less exposed areas.

Exposure to ambient air pollution, particulate matter (PM_{2.5-10}), nitrogen oxides (NO and NO₂) and ozone is associated with the higher prevalence and incidence of T2D, and excess mortality in T2D population. This is significantly amplified in overweight and obese individuals, thus patients with CV disease and coexisting diabetes are at the most vulnerable.

Exposure to air pollution also worsen MetS. High levels of ozone, PM₁₀ and CO₂ can potentially increase the risk of dyslipidemia and development of the MetS.

Long-term exposure to ambient air pollution may increase the odds of metabolic dysfunction-associated fatty liver disease (MAFLD), especially in individuals who had unhealthy lifestyle habits and with central obesity.

Developing countries, wherein the burden of air pollution and NCDs are emerging, are the most threatened.

Bushfire smoke contains a complex mixture of particles and gases that are chemically transformed in the atmosphere and transported by the wind. The smoke and ash produced by bushfires can significantly worsen air quality, especially level of PM_{2.5}.

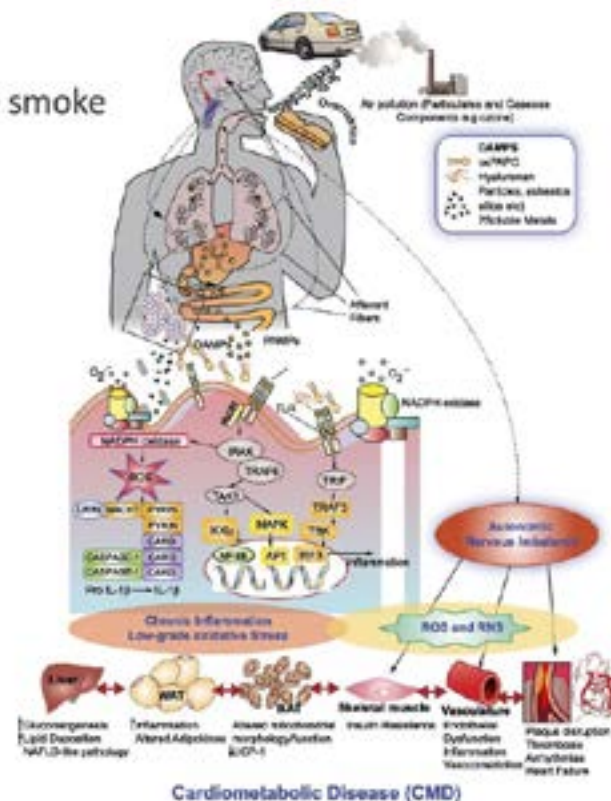
Smoke exposure, short- and long- term, is known to exacerbate existing obesity and T2D.

Catastrophic bushfires lead to worsening asthma outcomes, particularly in obese individual.

CC impacts on metabolic disorders

Potential pathways | ambient air pollution and bushfire smoke

Hypothesized mechanisms of air pollution-mediated cardiometabolic disease wherein inhalational or nutritional signals either directly or via the generation of signals such as DAMPs may serve to activate innate immune mechanisms such as the TLR and NLR.



DOI: 10.1371/journal.pmed.1003767
DOI: 10.2337/db12-0190

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Figure Legend

Hypothesized mechanisms of air pollution-mediated cardiometabolic disease wherein inhalational or nutritional signals either directly or via the generation of signals such as DAMPs may serve to activate innate immune mechanisms such as the TLR and NLR.

API, activator protein 1; CARD, caspase activation and recruitment domain; IKKb, IKB kinase b; IRAK, interleukin receptor-associated kinase; IRF3, interferon regulatory factor 3; MAPK, mitogen-activated protein kinase; MyD88, myeloid differentiation primary response gene 88; NAFLD, nonalcoholic fatty liver disease; PAMP, pathogen-associated molecular pattern; PAPC, palmitoyl-arachidonyl phosphocholine; RNS, reactive nitrogen species;

ROS, reactive oxygen species; TAK, transforming growth factor- β -activated kinase; TBK, TANK-binding kinase 1; TRAF, TNF receptor-associated factor; TRIF, Toll/IL-1 receptor-domain-containing adapter-inducing interferon- β ; UCP-1, uncoupling protein-1; WAT, white adipose tissue. (A high-quality digital representation of this figure is available in the online issue.)

→ DOI: 10.5696/2156-9614-9.22.190608

→ DOI: 10.5772/39004.

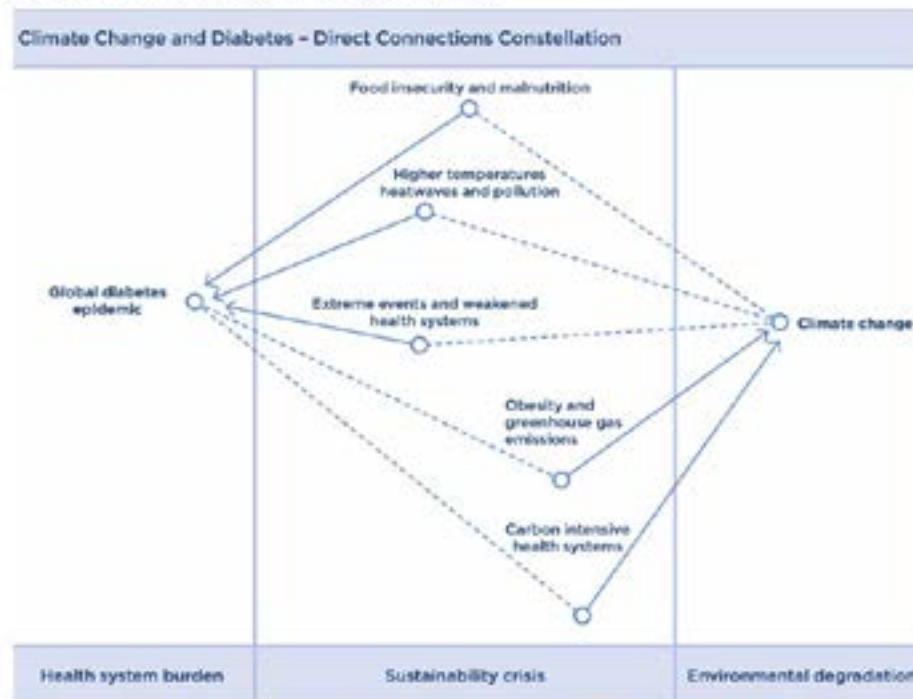
→ DOI: 10.1016/j.jhep.2021.10.016.

→ DOI: 10.1016/j.anai.2015.01.018

→ doi:10.1371/journal.pmed.1003767.

→ doi: 10.2337/db12-0190.

CC and diabetes: direct connections



<https://ncdi.alliance.org/sites/default/files/ncdi%20Diabetes%20and%20Climate%20Change%20Policy%20Report.pdf>, accessed 10 October 2022

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Impact of CC on health of people with diabetes / risk of diabetes

Exposure to extreme heat ➔ increased morbidity and mortality from heatstroke

Exposure to heat waves with high air pollution ➔ increased mortality from heart attack

Extreme weather conditions and natural disasters (e.g., heatwaves, hurricanes, floods, fires, drought etc.):

devastation of living conditions and the resource scarcity ➔ urban slum growth and increase resource scarcity ➔ increased obesity and diabetes risk

destruction of healthcare infrastructure and delivery of care ➔ life-threatening exacerbating of disease

Geo-environmental diabetology - describes how geophysical phenomena affect people with diabetes

➔ doi: 10.4158/EP09344

Impact of CC on food security and T2D risk

Climate extremes and natural disasters ➔ water scarcity and the destruction of crops agricultural production and the food supply ➔ food shortage, rising prices ➔ food insecurity

It is estimated that half the world will experience food shortages by the end of the 21st Century

Food insecurity ➔ malnutrition /over- and under- nutrition ➔ exacerbating T2D and related NCDs risk

Maternal under-nutrition in pregnancy increases the risk of the infant obesity and T2D in later life

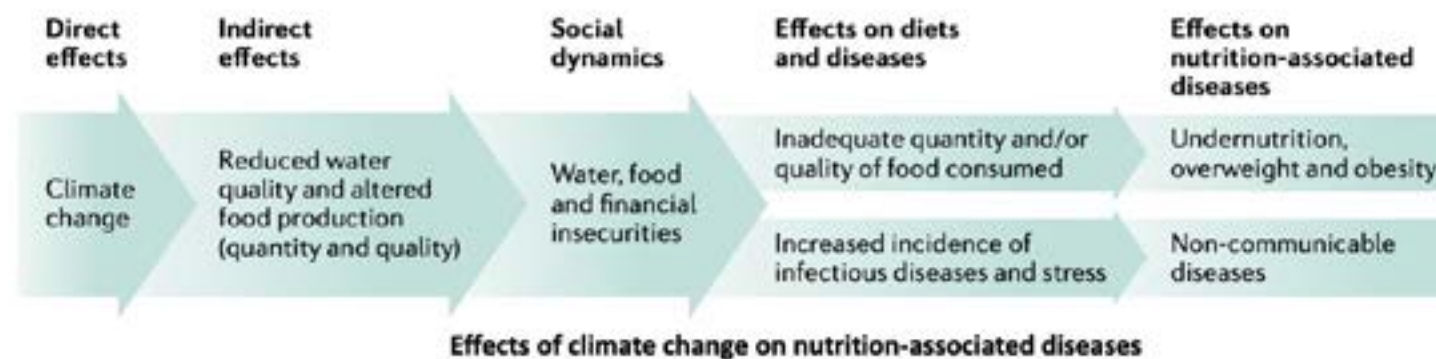
Disrupted traditional food supplies ➔ fresh produce expensive and scarce ➔ increases consumption of imported and processed food ➔ exacerbating T2D risk

Low-income populations and indigenous people, who follow traditional diets are particularly at risk

CC and diabetes: direct connections

Impact of CC on food security and T2D risk

Reduced quality and quantity of crops result in increased food and financial insecurities leading to **malnutrition** (undernutrition and obesity) and **diet-related NCDs**, such as DM and CVD



The impact obesity and diabetes on GHG emissions

Increasing obesity prevalence → increases energy consumption / GHG emissions from massive food production

It has been estimated that a population in which 40% of people are obese requires 19% more food energy than a population in which there is a normal BMI distribution.

The rising burden of NCDs and exacerbating diabetes-related complications → rising financial burden and increasing GHG emissions generated by health care systems.

Preventing and management of diabetes need to be prioritised in order to decrease already large carbon footprint of health care system.

Urgent need to reorient health systems from the traditional focus on acute care to a more proactive and preventative continuing care model.

→ <https://ncdalliance.org/sites/default/files/rfiles/IDF%20Diabetes%20and%20Climate%20Change%20Policy%20Report.pdf>
 ↘ accessed 10 October 2022

CC and diabetes: indirect connections

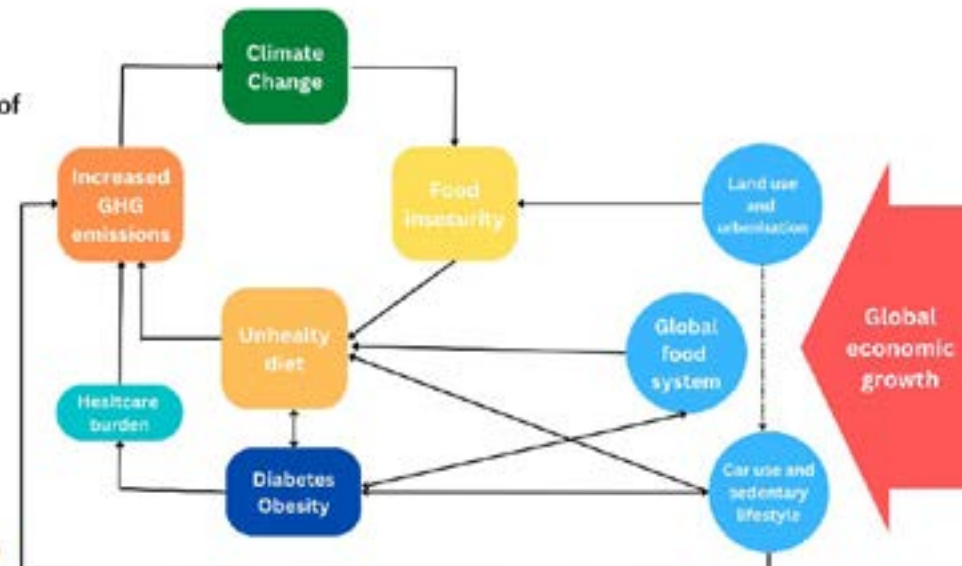
The shared vectors

Global economic growth as the main driver of GHG emission has several synergistic sociocultural vectors:

1. land use and urbanization,
2. motorized transportation, and
3. global food system

which influence:

- CC by **excess GHG emissions**
- the diabetes/ obesity epidemic by **unhealthy diet and physical inactivity**



Depiction of a vicious cycle of CC and diabetes/obesity interconnections
(blue circle are their shared vectors)

DOI: 10.1111/dme.14971

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ref. 1001-20011-14030-1-ED-00000000

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The shared vectors | urbanisation and transport

Rapid and unplanned urbanization → more carbon-intensive transports, slum growth, an urban heat island (UHI) effect, increased air pollution and resource degradation → sedentary lifestyle: physical inactivity and unhealthy diet → increasing transport emissions and diabetes risk.

Urban cities are responsible for:

70% of GHG emissions, with cars contributing to 30% of the air pollution

every extra hour spent in a car each day increases the risk of obesity by 6%

increased energy costs (e.g., for air conditioning), air pollution, heat-related illness and mortality

enhanced physical inactivity

increased demand for meat and cheap processed foods

→ DOI: 10.1111/dme.14971

The shared vectors | the global food system

Changing in the global food system (GFS) → nutrition transition → increasing diabetes risk and threatens the environment.

Multiple pathways for that impact: soil fertility, mass monocultural production, water

availability, reduced food yield, reduced food nutrient concentration and bioavailability, mass livestock production etc.

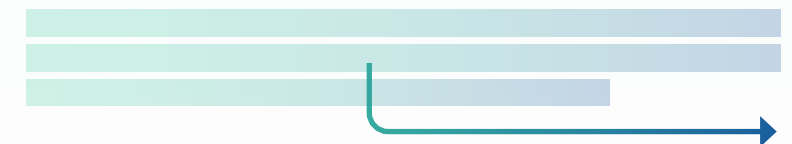
Accounts for ~ 30% of global GHGs and contribute to environmental and biodiversity degradation; reduces people's access to healthy diets, increasing their risk of poor health and diet-related diseases.

In 2020, two billion people were food insecure, and three billion people could not afford a healthy diet.

Considerable inequalities in the global consumption: developed countries consuming nearly ten times the amount of red meat and contribute 41% more emissions compared with developing countries. These inequalities are exacerbated by the extremely high cost of a plant-based diet that is much more affordable in higher-income countries.

Unsustainable the global food system includes:

Unsustainable agriculture produces up to a third of GHG emissions worldwide, due to increasing demand for animal products while the carbon cost of meat is seven times higher than that of vegetables. Animal products are nutritionally important, but red meat and processed meats are associated with obesity, T2D and NCDs.



CC and diabetes: indirect connections

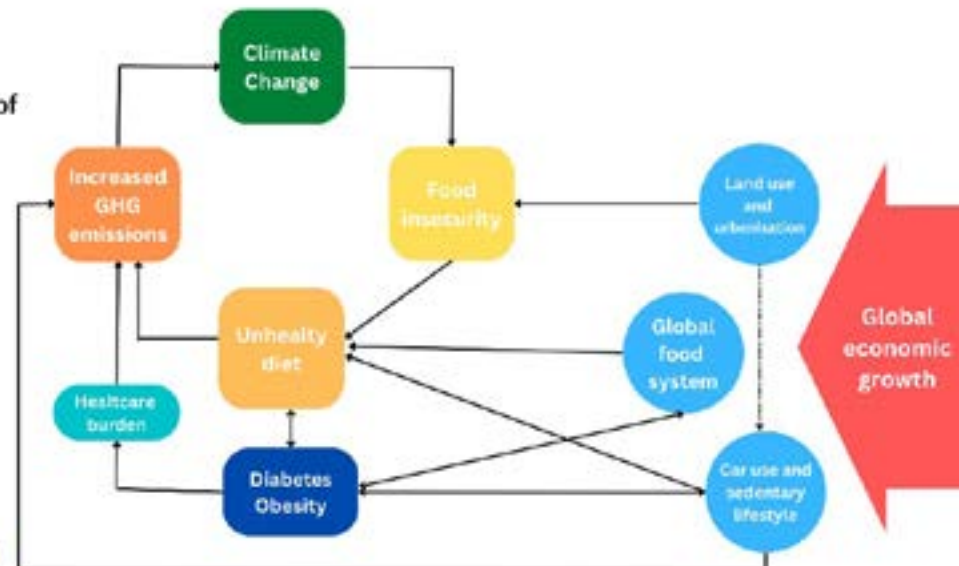
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Depiction of a vicious cycle of CC and diabetes/obesity interconnections
(blue circle are their shared vectors)

DOI: 10.1111/dme.14971

Increasing of ocean temperatures by CC, reduce marine phytoplankton - the primary producers of omega-3 polyunsaturated fatty acids (PUFAs).

Human diet deficient in omega-3 PUFAs are associated with an increased risk for the development of T2D.

→ DOI: 10.1111/dme.14971

Rapid development of food production increases the availability and affordability processed and energy-dense foods; carbon intensive production, transport and storage; forming of urban slums; harmful land clearing and deforestation etc.

Shifting of dietary pattern-nutrition transition from traditional diets based on grains, locally grown vegetables and fruits towards diets high in processed foods, saturated fats and sugar, and low in fibers

High levels of obesity, diabetes and other NCDs

Over-nutrition correlates with socio-economic inequality

Under and over-nutrition can co-exist in the same countries, communities and even households.

→ doi: 10.1038/s41572-021-00329-3

How changes in food quality impact diabetes risk?

Intensive agriculture affects food quality reducing micronutrients in plant-based foods

Reduced dietary micronutrients: zinc, magnesium, chromium, copper, manganese, iron, selenium, vanadium, B-group vitamins and antioxidants reduce insulin sensitivity or secretion and contribute to an increased risk of T2D.

How health officials develop strategies and programs to help communities prepare for the health effects of CC?

- Improving climate resiliency and reducing extreme heat impacts entails the development of suitable public health programs (e.g., heat warnings, heat-health action plans) and education of healthcare providers to better recognize, manage and communicate those health impacts of CC.
- CDC's Building Resistance Against Climate Effects (BRACE) framework consists of five sequential steps:



The following steps:

03 – assessing the most suitable public health interventions for the identified health impacts of greatest concern / co-benefit strategies

04 – developing and implementing a climate and health adaptation plan / risk management of extreme geological and weather events / prevention measures

<https://www.cdc.gov/climateandhealth/BRACE.htm>, accessed 15 February 2023

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ref. 2021-ZHU01-KA220-HED-000050972

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How health officials develop strategies and programs to help communities prepare for the health effects of CC?

- According to **CDC's BRACE framework** following step is: assessing the most suitable public health interventions that simultaneously tackle the common predisposing vectors of metabolic disorders and CC – **Co-benefit strategies**

- **Co-benefit strategies** that aim to transform:

high-carbon obesogenic environment → **active low-carbon living**

Health | Economic | Environmental benefits and Sustainable Development

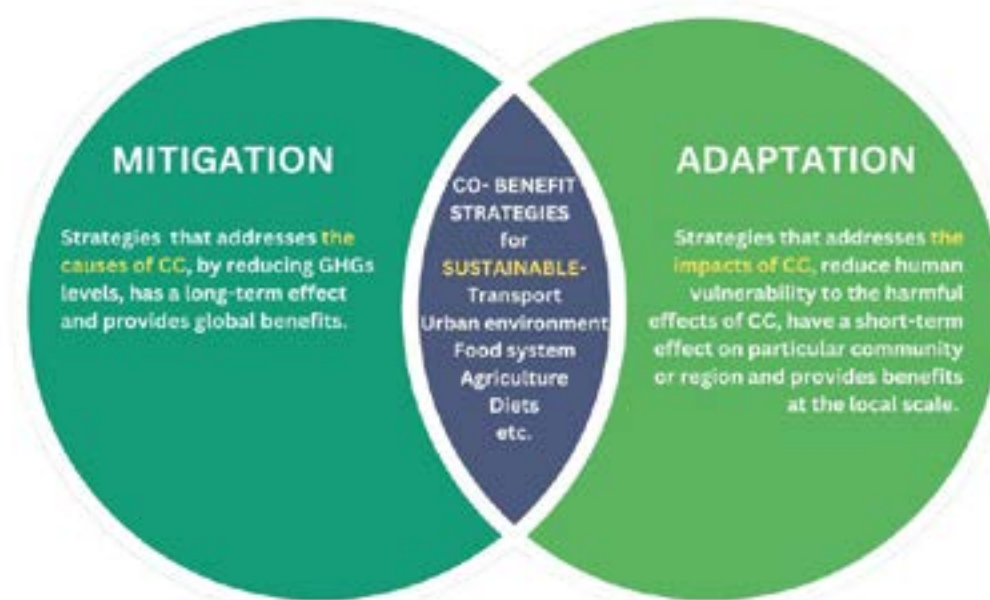


- **Co-benefit strategies** that enable **lifestyle changes** and **sustainable urbanisation**

(1) transport and urban planning policies and

(2) food policies

Mitigation | Adaptation | Co-benefit strategies



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ref. 10101-2018-1-KA201-HE0-00004872

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Co-benefit strategy: ACTIVE TRAVEL

More distances walked and cycled by individuals could be managed with well planned urban environments, through transport policies and urban design:

Switching transportation modes to low-carbon transportation :

By shifting from vehicle transportation to 'active transport ,such as: walking and cycling, combined with public transport powered by renewable energy

By transition to ultra-low emission vehicles

By application of vehicle restrictions in cities and limitation of car speeds.

Implementing 'active design' into urban design:

Compact, walkable urban environments - 'built environment'

Greater street connectivity and balanced mix land use

Increasing bicycle lanes and parking areas in urban area

Incorporates green spaces within communities, transportation routes and floodplains

Accessible welfare community facilities especially in preventive care to improve the prevention of chronic diseases including T2DM

Built environment - walkable urban environments

'Built environment' contribute to lifestyle modification: more walkable or activity-friendly environments provide more opportunities for physical activity and potentially decrease the burden of obesity and diabetes in the population.

Neighborhood socioeconomic status, food environment, air pollution and green space coexist and potentially interact with the built environment to affect metabolic health

'Nationwide Nurses' Health Study: poor air quality is often located in areas of high walkability and commuting cycling networks are often developed alongside major traffic routes.

Planning and construction of cycling infrastructure needs to be done in ways that limit personalized exposure to air pollution


→ DOI: 10.1088/1755-1315/1016/1/012054

→ DOI:10.1016/j.earlhumdev.2020.105220

→ DOI:10.1002/9781119807216.ch1

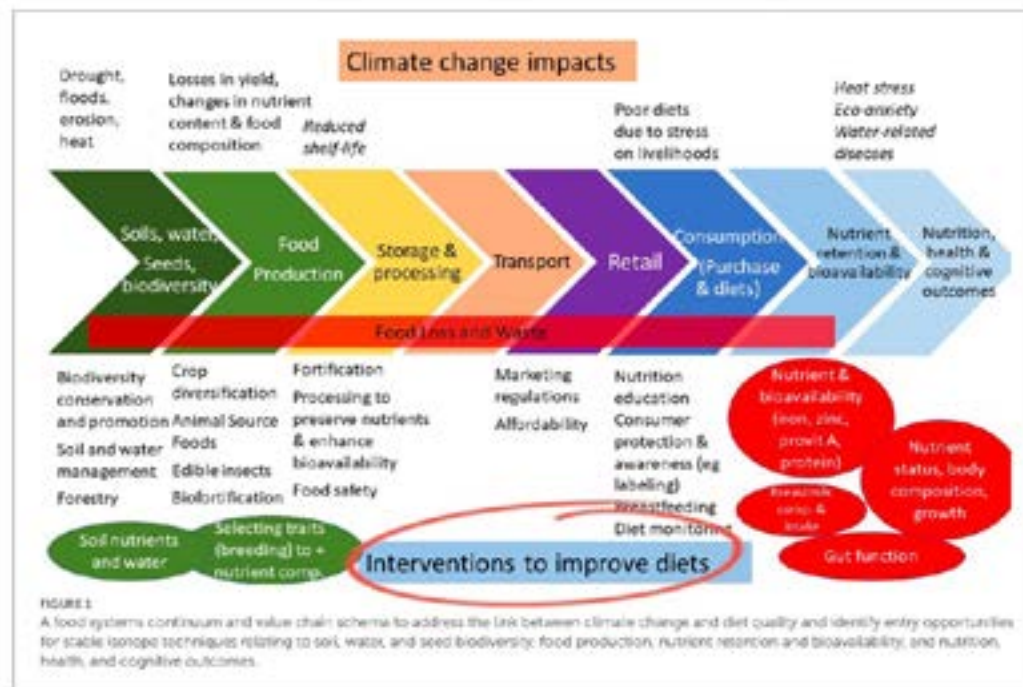
→ DOI: 10.1530/JOE-20-0487.

Metabolic health co-benefits of ACTIVE TRAVEL

Action	Health co-benefit	CC Mitigation
<p>ACTIVE TRAVEL</p> <ul style="list-style-type: none"> - Policies that reduce overall vehicle use and increase walking and cycling - Well planned urban environments, through transport policies and urban design 	<ul style="list-style-type: none"> - Reduced risk of metabolic disorders - obesity, T2D, MetS etc. - Benefits for metabolic health: encouraging physical activity, social connectivity, improving air quality and reducing urban heat island effects. <ul style="list-style-type: none"> • Physically active individuals reduce their risk of developing type 2 diabetes by up to half (<i>WHO</i>) • It was shown that active commuting is associated with about a <u>10% decrease in risk for CVD</u> and a 30% decrease in T2D risk. (<i>WHO</i>) - More walkable or activity-friendly environments provide more opportunities for physical activity and decrease the burden of obesity and diabetes in the population. 	<ul style="list-style-type: none"> - Reductions in GHG emissions and air pollution

DOI: 10.1186/s12966-015-0223-3.

Transforming food systems to improve diets



Local food production / affordability of nutritious food

Urban agriculture - urban farms, school gardens and farmer markets / local access to local fresh and seasonal foods

Understandable nutritional information through food labelling, dietary guidelines and awareness campaigns.

→ doi: 10.1016/j.earlhumdev.2020.105220.

→ DOI: 10.3389/fclim.2022.941842.

Policies for CC mitigation need to combat both over- and under-nutrition, and much more:

The coexistence of undernutrition, obesity and micronutrient deficiencies - the triple burden of malnutrition is spreading and affecting almost every country in the world.

Obesity affects millions of people, and several billion suffer from diseases caused by vitamin- or mineral-deficient diets, known as micronutrient deficiencies, according to the UN agriculture chief, who called for transformative changes to our food systems !!!

→ | <https://news.un.org/en/story/2018/12/1027441>

Co-benefit strategy: Food policies

Food policies that encourage shifting the diet from a highly processed and animal-based diet to a 'sustainable diet'

'Sustainable diets' have low environmental impacts, deliver food and nutrition security and support healthy life for present and future generations.

To ensure sustainable diets we need: sustainable food systems coupled with sustainable agriculture

Sustainable food systems support an increasing population with a diet low in animal products and processed foods, and high in locally-produced fruit and vegetables.


Reducing production and consumption of animal products - a crucial strategy to reduce GHG emissions, improve diets and reduce exposure to obesity and T2D risk.

Dietary diversification, fortification, biofortification, and the inclusion of alternative protein sources (e.g., edible insects) are some of the available alternative options.

Sustainable agriculture - food security in an efficient, environmental sound and socially responsible way.

Cutting the production of processed food, balanced with ensuring food security and nutrition for all

Metabolic health co-benefits of PLANT-BASED DIETS

Action	Health co-benefit	CC Mitigation
<p>PLANT-BASED DIETS</p> <ul style="list-style-type: none"> - Reducing reliance on red meat consumption and prioritising healthier alternatives - Various diets and choices available depending on the region, individual, and cultural context 	<ul style="list-style-type: none"> - Have a role in reducing the risk of T2D and major diabetes-related macrovascular and microvascular complications. - As a part of lifestyle changes are effective tools for T2D prevention and management. - The type and source of carbohydrate (unrefined versus refined), fats (monounsaturated and polyunsaturated versus saturated and trans), and protein (plant versus animal) play a key role in the prevention and management of T2D. - Potential mechanisms of a plant-based diet in <u>enhancing insulin resistance</u>: maintaining of a healthy body weight, increases in fiber and phytonutrients, food-microbiome interactions, and decreases in saturated fat, advanced glycation end-products, nitrosamines, and heme iron. 	<ul style="list-style-type: none"> - Reductions in GHG emissions and water consumption

DOI:10.11909/j.issn.1671-5411.2017.05.009.

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CASE STUDY

How to best prepare for management of diabetes under situations of extreme geological and weather events?

- **Diabetes self-management** is becoming more complex in CC era.
- Day-to-day management and treatment protocols of diabetes should take into account weather data.
 - ✓ Careful attention must be paid to **replenishing fluid regularly**
 - ✓ Patients should be encouraged **not to exercise outside, but in air-conditioned facility** during the hottest times of the day
 - ✓ It may be necessary **to make seasonal changes** in diabetes therapy to achieve consistency in glycemic control.
 - ✓ Patients should be advised to be on the alert for changes in their glucose levels when they are in the heat and that **changes in their insulin regimen** may be needed.
 - ✓ **Keeping insulin cool** and **oral hypoglycemic agents at controlled temperatures**, as well as **glucometers and insulin pumps at optimal temperature ranges for performance**.



DOI: 10.4158/EP09344.

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Geo-environmental diabetes management | national level

- Climate and Health Adaptation Plan for diabetes management during extreme geological and weather events, namely **Geo-environmental diabetes management**
- A multilevel approach will be needed when developing a strategy for geo-environmental diabetes management. In regions at risk for geological or extreme weather events there is need for coordinated efforts of the **government, NGOs, and clinical institutions**:
 - ✓ Develop, implement, and disseminate preparedness plans with targeted information for diabetes patients
 - ✓ Develop contingency planning for emergency transport of the most susceptible patients and actions in case of potential barriers to accessing care
 - ✓ Anticipate the quantity of supplies and medications for patients
 - ✓ Mitigate disparities in diabetes disaster preparedness

DOI: 10.1177/193229681100500402.

Geo-environmental diabetes management | health care providers

- Health authorities, medical professionals and care providers should provide targeted information of health effects from heat-waves
- Residents need to integrate patient- and location-specific climate risks into more effective disease prevention and treatment plans
- General practitioners (GPs) need to include as a substantial component an understanding of community-based factors that shape health and the delivery of health services
- Physicians need to provide guidance in routine clinical encounters on lifestyle choices that improve individual health in the long term
- More efforts need to be done to reduce the carbon footprint of healthcare:
 - ✓ Simple interventions like stopping the use of halogenated anaesthetic agents, reducing or stopping the use of single-use medical devices (such as insulin pens), improving waste sorting and recycling, and promoting remote consultations to reduce travel.

DOI: 10.1056/NEJMc2210623.

Geo-environmental diabetes management | health care providers

Particularly care for T2D patients: **What GPs should do?**

- ✓ identify T2D patients with cardiovascular complication or chronic kidney disease, who may require a certain individualized management plan
- ✓ routinely conduct pre-summer medical assessment and counselling relevant to heat exposure for people with diabetes
- ✓ be aware of the potential side effects of the medicines prescribed and adjusting dosage if necessary
- ✓ more frequent monitoring and check-ups during extreme weather
- ✓ measures to ensure that vulnerable T2D patients stay indoors and have access to cooling systems safely during extreme heat periods
- ✓ preparedness plans for medication and support for climatic disasters
- ✓ comprehensive campaigns for increasing public awareness, education, and advising patients how to cope with numerous risks
- ✓ education related to weather terms such as temperature, humidity, and heat index are needed

ISBN 978 92 890 7191 8
DOI: 10.1088/1755-1315/1016/1/012054

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Geo-environmental diabetes management | health care professional

Additional education of health care professionals:

- ✓ Updating of knowledge on heat pathologies
- ✓ Identification of at-risk people and situations
- ✓ Knowledge of prevention measures and principles of care (or nursing)
- ✓ Knowledge of warning systems and health organizations in case of a crisis
- ✓ Knowledge of drugs (at-risk drugs, how to adapt the treatment, correct storage of drugs)

Health professionals need **to be proactive** in:

- ✓ Promoting active travel and sustainable eating practices
- ✓ Implementing adaptation measures to minimize distress in people with diabetes
- ✓ Enforcement of climate change mitigation in their lives and in health systems
- ✓ Addressing sustainability in managing diabetes
- ✓ Further research to better advice patients

ISBN 978 92 890 7191 8

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Geo-environmental diabetes management | advanced level



Certain technologies could be of great importance in geo-environmental diabetes management

- ✓ **Geographic information systems** for mapping urban areas with increased patient vulnerability to heat
- ✓ **Wireless transmission of personal blood glucose data** by patients to a centralized electronic health record system for early detection of epidemic disease outbreaks
- ✓ **Centrally monitoring individual glucose control** during extreme weather for early intervention (e.g., a phone call to the patient to provide advice on whether to seek medical attention)
- ✓ **Real-time methods** for communication of weather advisories to patients with diabetes (e.g., transmission of mobile text messages by local area weather services)

doi: 10.1177/193229681100500402.


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Preventive measures | patient level

- Patients with diabetes must also take personal steps to be prepared. They should be familiar with guidelines for disaster preparedness tailored for them.
- They also need to prepare personal **diabetes emergency plan and supply kit**, during and after an emergency to maintain daily diabetes management and to help prevent acute health problems.
- The key issues they need to consider:
 - ✓ Be identified as patient with diabetes, wearing visible medical ID
 - ✓ Prevent very high blood glucose
 - ✓ Stay well-hydrated
 - ✓ Beware of hypoglycemia
 - ✓ Beware of infection
 - ✓ Maintain medication schedule
 - ✓ Maintain meal plan
 - ✓ Prepare a portable emergency kit
 - ✓ Prepare a list of emergency contacts



Clinical diabetes programs operating in regions at risk for geological or extreme weather events should have incorporated information into their routine diabetes educational programs.

<https://www.aace.com/sites/default/files/2021-03/Diabetes-Emergency-Web-Download%20Checklist.pdf>
accessed 18 February 2023

KEY MESSAGES

- The climate crisis and diabetes/ obesity pandemics are interconnected health issues which have common predisposing vectors and magnify each other's impacts.
- The three shared common global vectors are increased urbanisation, increased reliance on mechanized transportation and increased production and consumption of meat and ultra-processed foods
- Both crises have shared common solutions – public health actions for lifestyle changes and sustainable urbanisation
- Health professionals should guide an joint action on tackling climate – health issues

SUGGESTED READINGS

1. DOI: [10.1002/ajhb.23460](https://doi.org/10.1002/ajhb.23460), Gildner TE, Levy SB. Intersecting vulnerabilities in human biology: Synergistic interactions between climate change and increasing obesity rates. Am J Hum Biol. 2021 Mar;33(2):e23460.
2. DOI:[10.1002/9781119807216.ch1](https://doi.org/10.1002/9781119807216.ch1), Urban Ecology and Global Climate Change (pp.1-29),
3. DOI: [10.11909/j.issn.1671-5411.2017.05.009](https://doi.org/10.11909/j.issn.1671-5411.2017.05.009), McMacken M, Shah S. A plant-based diet for the prevention and treatment of type 2 diabetes. J Geriatr Cardiol. 2017 May;14(5):342-354.

TEST YOUR KNOWLEDGE :

Student have to select ALL the correct answers in each question (multiple answer):

1. What are the possibly pathways for worsening of the disease in patients with diabetes exposed to extreme heat?
 - a) reduced skin blood flow
 - b) increased heat loss
 - c) reduced sweat rate
 - d) increased body temperature
2. What elderly population makes particularly vulnerable to heat exposure?
 - a) age-related chronic health conditions
 - b) impaired fluid and electrolyte balance
 - c) increased skin blood flow
 - d) polypharmacy
3. Which are the main impactful sociocultural vectors that CC and diabetes/obesity share?
 - a) rapid and unplanned urbanisation
 - b) higher prevalence of dehydration
 - c) carbon-intensive transport
 - d) mass livestock production

TEST YOUR KNOWLEDGE :

4. What are the aim of metabolic health co-benefits strategies?
 - a) active low-carbon living
 - b) lifestyle changes
 - c) reduction of the healthcare carbon footprint
 - d) sustainable urbanization
 - e) reduction of air pollution
5. How neighborhood design features may improve healthy living?
 - a) accessible public transit
 - b) proximity of farmer's market
 - c) a lot of green spaces
 - d) urban slums
 - e) high walkability
6. How to accomplish sustainable eating practices?
 - a) eat more plant-based food
 - b) reduce consumption of highly processed food
 - c) choose locally-grown food
 - d) eat in nearby restaurant
 - e) buy seasonal produce

Thank you for you attention!

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Center for Health, Exercise and Sport Science – Novi Sad, Serbia



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Impact of temperature on kidney function and renal diseases

The Kidneys

- Highly vascularized organs
- The **kidneys** play a critical role in:
 - the compensatory physiological mechanisms of **thermoregulation**
 - **blood pressure regulation**
 - maintenance of the overall **balance of water and electrolytes**, and
 - **acid/base balance**

The Kidneys

- These regulation processes could provoke compensatory **responses from the kidneys**:

- Physiological actions in order to heat stress



redirected blood flow away from the kidneys to the skin to offload heat and promote heat loss

- Heat stress combined with dehydration



combined demands can be physiological or pathophysiological

Kidney Diseases

- Increasing incidence and prevalence



increasing mortality

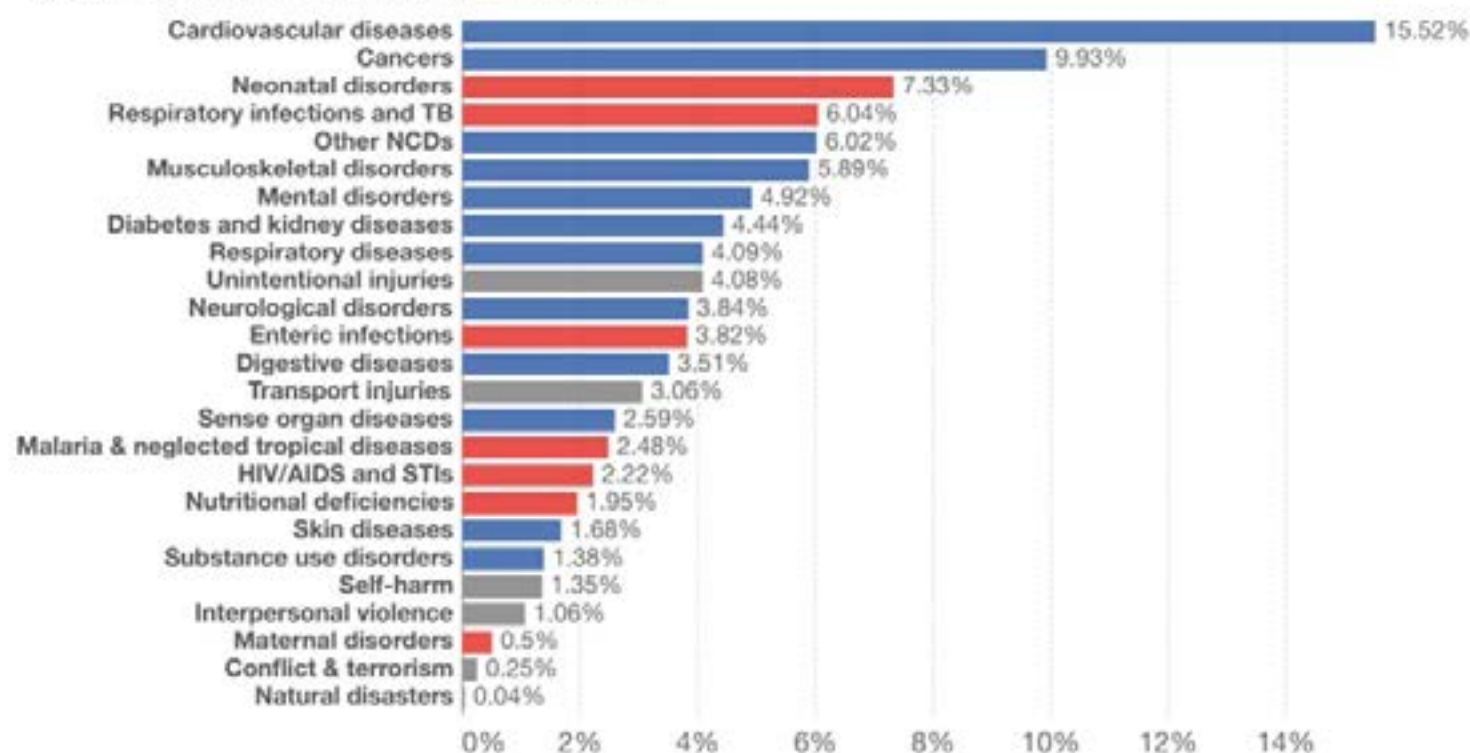
- Disability-adjusted life-years (DALYs) for kidney disease increased from 19 million in 1990 to 36 million in 2017 (GBD 2017)

Kidney Diseases

Share of total disease burden by cause, World, 2019

Our World
in Data

Total disease burden, measured in Disability-Adjusted Life Years (DALYs) by sub-category of disease or injury. DALYs measure the total burden of disease – both from years of life lost due to premature death and years lived with a disability. One DALY equals one lost year of healthy life.



Source: IHME, Global Burden of Disease (2019)

OurWorldInData.org/burden-of-disease • CC BY

Note: Non-communicable diseases are shown in blue; communicable, maternal, neonatal and nutritional diseases in red; injuries in grey.

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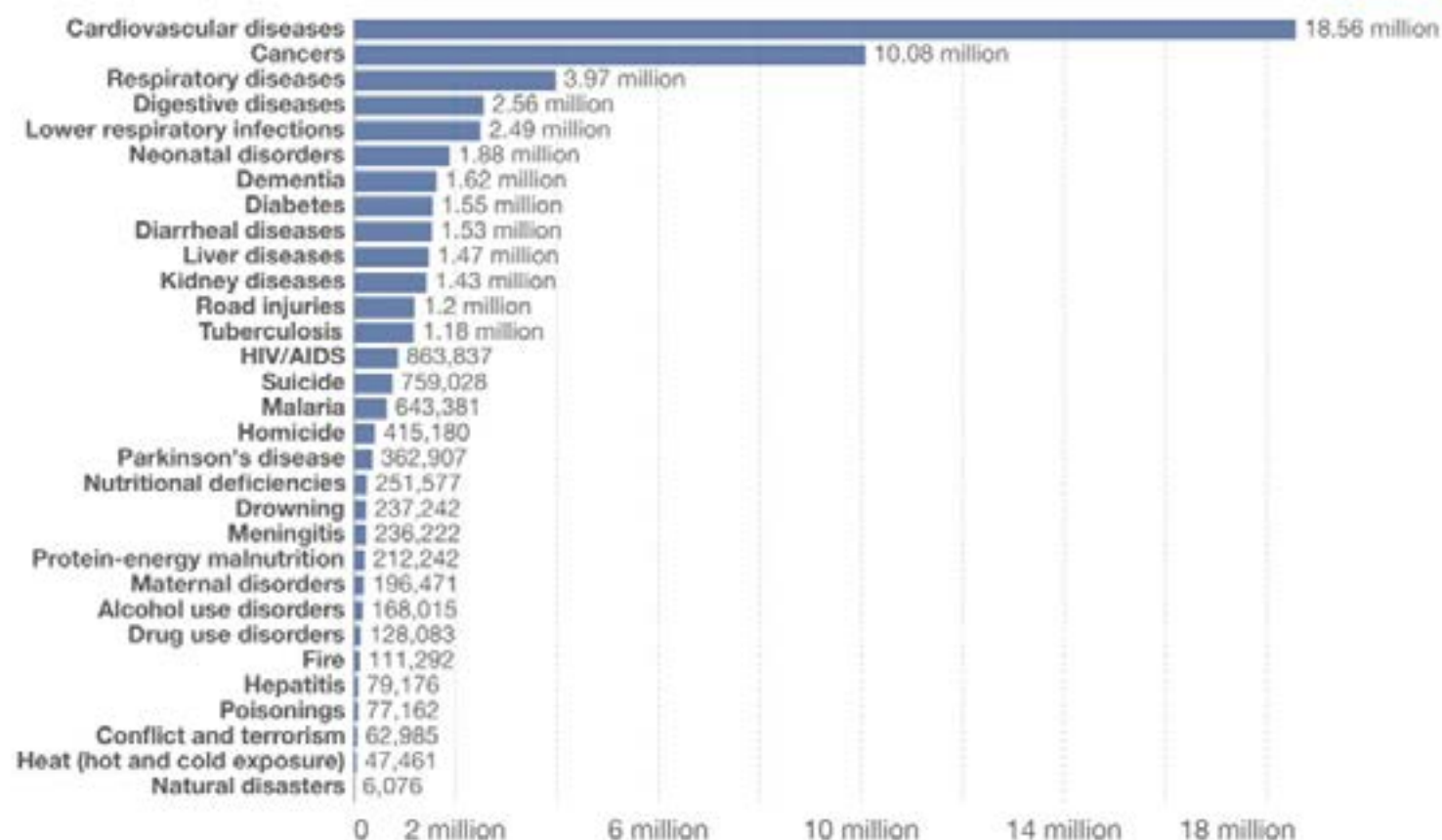
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Kidney Diseases

Number of deaths by cause, World, 2019

Our World
in Data



Source: IHME, Global Burden of Disease (2019)

OurWorldInData.org/causes-of-death • CC BY

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Temperature and kidney diseases

- Important risk factor for many adverse health outcomes, including mortality and morbidity for specific causes
- Chronic kidney disease (CKD) is an important cause of disease and economic burden due to the expensive renal replacement therapy for end-stage kidney disease
- In 2017, 697 million people were diagnosed with CKD, and 1.2 million deaths were attributed to CKD worldwide, a 41.5% increase in mortality rate from 1990.
- Among the risk factors for CKD, diabetes, hypertension, and glomerulonephritis are known to be the most common causes.

Kidney Diseases

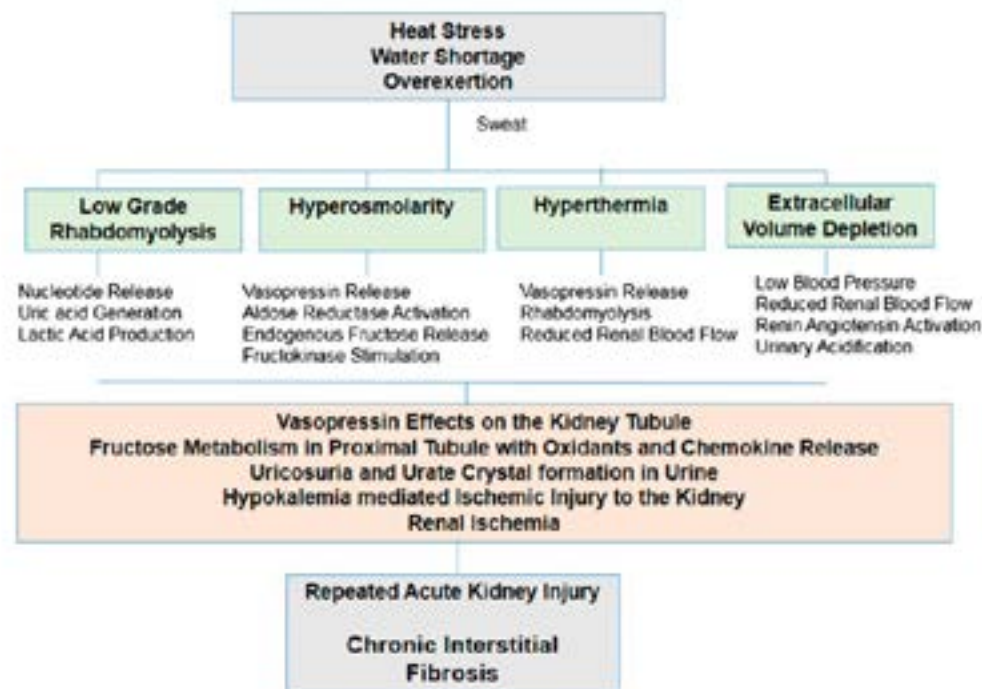
Risk factors

- diabetes
- high blood pressure
- established heart problems (heart failure or heart attack) or have had a stroke
- family history of kidney disease or kidney failure
- obese with a body mass index (BMI) 30 or higher
- smoking
- old age
- history of acute kidney injury

Climate change and heat stress nephropathy

- Climate-related extreme heat exposure
- Inadequate hydration can lead to chronic kidney disease (CKD)
- Epidemics of CKD consistent with heat stress nephropathy
- Heat stress nephropathy may represent one of the first epidemics due to global warming.

Climate change and heat stress nephropathy



→ This would involve the activation of the RAS, which also plays an important role in kidney disease

Heat stress nephropathy

- One of the consequences of climate-related extreme heat exposure is dehydration and volume loss, leading to acute mortality from exacerbations of pre-existing chronic disease, as well as from outright heat exhaustion and heat stroke.
- Recent studies have also shown that recurrent heat exposure with physical exertion and inadequate hydration can lead to chronic kidney disease (CKD) that is distinct from that caused by diabetes, hypertension.
- Epidemics of CKD consistent with heat stress nephropathy are now occurring across the world.

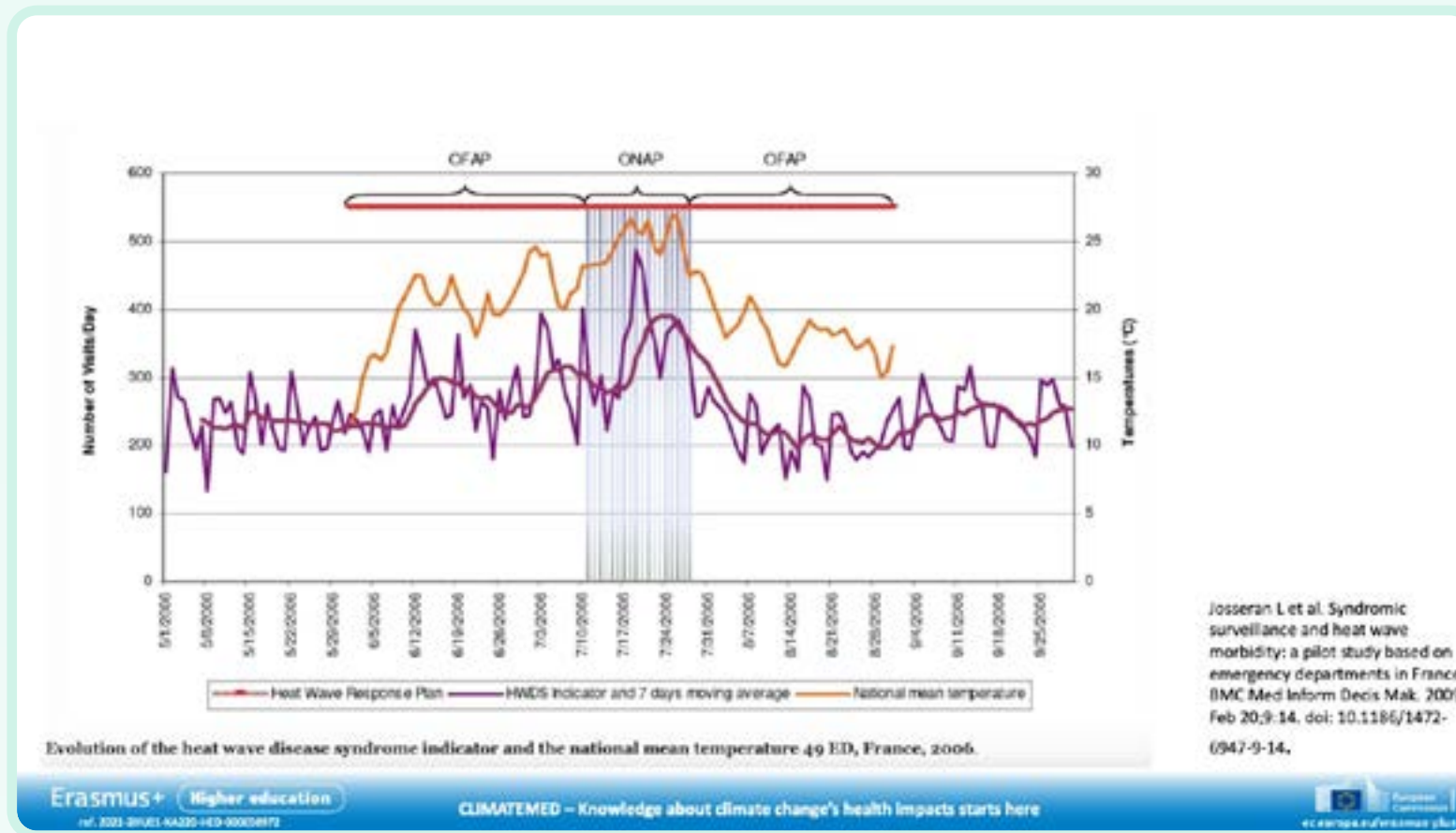
→ Heat stress nephropathy may represent one of the first epidemics due to global warming.

Development of chronic kidney disease associated with heat

- In addition to these mechanisms, there may be others involved, such as:
 - muscle damage due to strenuous physical exercise with onset of subclinical rhabdomyolysis,
 - intake of nonsteroidal anti-inflammatory drugs (NSAIDs) and
 - low blood pressure due to volume depletion.

→ In 2017, 697 million people were diagnosed with CKD, and 1.2 million deaths were attributed to CKD worldwide, a 41.5% increase in mortality rate from 1990.

→ Among the risk factors for CKD, diabetes, hypertension, and glomerulonephritis are known to be the most common causes.



Temperature and kidney diseases

→ The epidemiological evidence suggests that exposure to high temperature, defined as ambient temperature that are warmer than the optimum temperatures, is an important risk factor for many adverse health outcomes, including mortality and morbidity for specific causes

→ Chronic kidney disease (CKD) is an important cause of disease and economic burden due to the expensive renal replacement therapy for end-stage kidney disease

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→ The epidemiological evidence suggests that exposure to high temperature, defined as ambient temperature that are warmer than the optimum temperatures, is an important risk factor for many adverse health outcomes, including mortality and morbidity for specific causes

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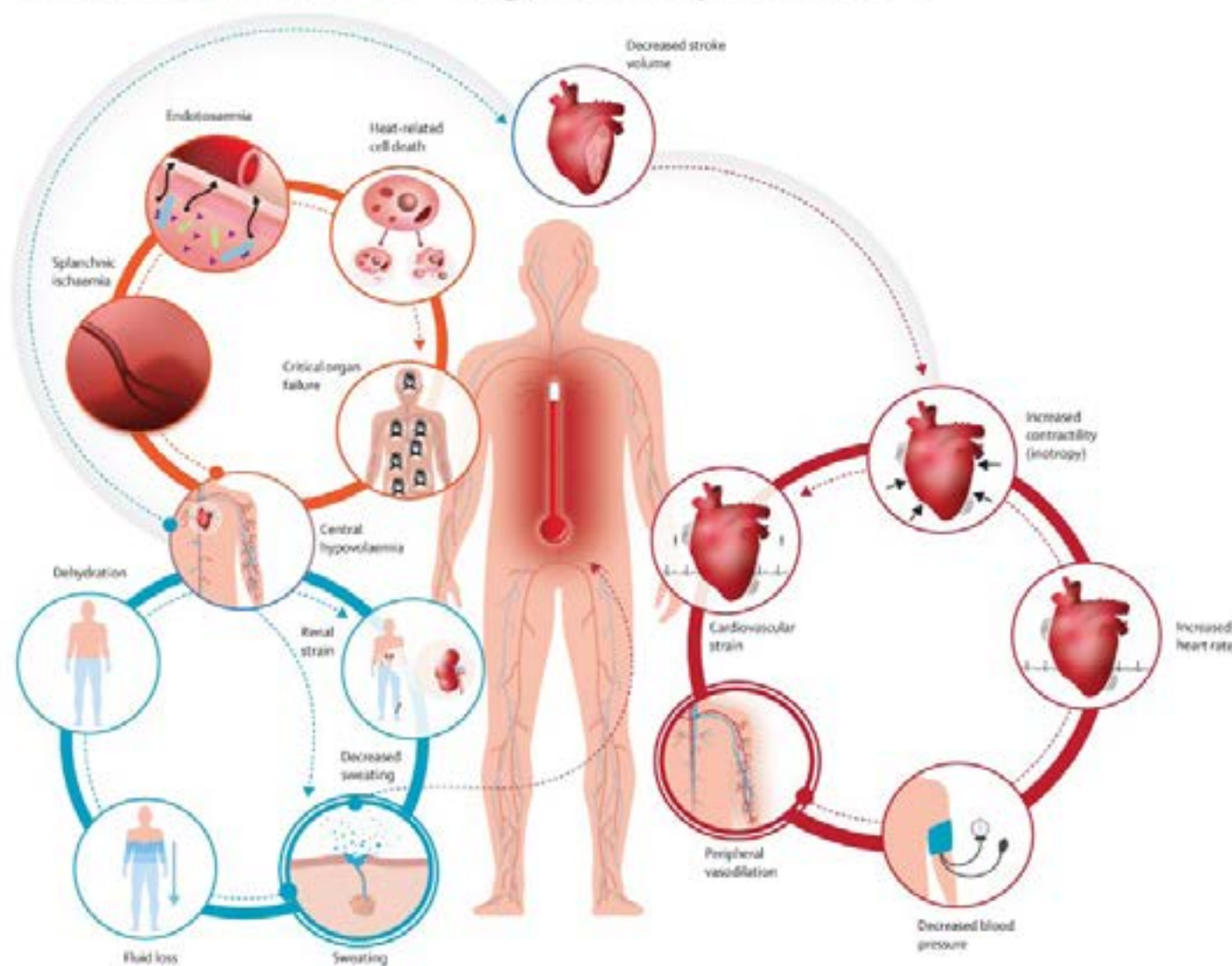
	Less than 75 years old				At least 75 years old			
	ONAP ¹		OFAP ²		ONAP ¹		OFAP ²	
	HWDS ³ ED Visits	HWDS ³ ED Visits as a proportion of total ED Visits	HWDS ³ ED Visits	HWDS ³ ED Visits as a proportion of total ED Visits	HWDS ³ ED Visits	HWDS ³ ED Visits as a proportion of total ED Visits	HWDS ³ ED Visits	HWDS ³ ED Visits as a proportion of total ED Visits
Malaise	1,808	2.46%***	5,554	1.85%	661	7.70%***	2,062	6.24%
Hyperthermia	98	0.13%*	115	0.04%	31	0.35%***	10	0.03%
Hyponatremia	59	0.08% (NS)	99	0.03%	139	1.62%***	187	0.57%
Dehydration	67	0.09% (NS)	112	0.04%	161	1.88%***	207	0.63%
Renal Colic	684	0.94%*	2,527	0.84%	19	0.22% (NS)	58	0.17%
Renal failure	59	0.08% (NS)	205	0.07%	57	0.66%*	170	0.51%
Total HWDS ³	2,775	3.78%***	8,612	2.87%	1,068	12.43%***	2,694	8.15%

* p < 0.05 ** p < 0.01 *** p < 0.001.

1: ONAP, 'On Alert' Period; 2: OFAP, 'Off Alert' Period; 3: HWDS, Heat Wave Disease Syndromes

Heat wave disease syndromes (visits/proportion) by age group and period, 49 ED, France summer 2006

Health risks of high temperature



Temperature, heat waves:
Cardiovascular diseases,
Respiratory diseases,
**Renal and metabolic
diseases**
Mental diseases

Heart

Aging is associated with reduced myocardial contractility. This leaves older adults less capable of augmenting cardiac output in response to heat-related dehydration and metabolic burden

Older adults are also more likely to be on medications such as diuretics and beta blockers, which further blunt the ability of the heart to respond to environmental stress-related cardiac demand



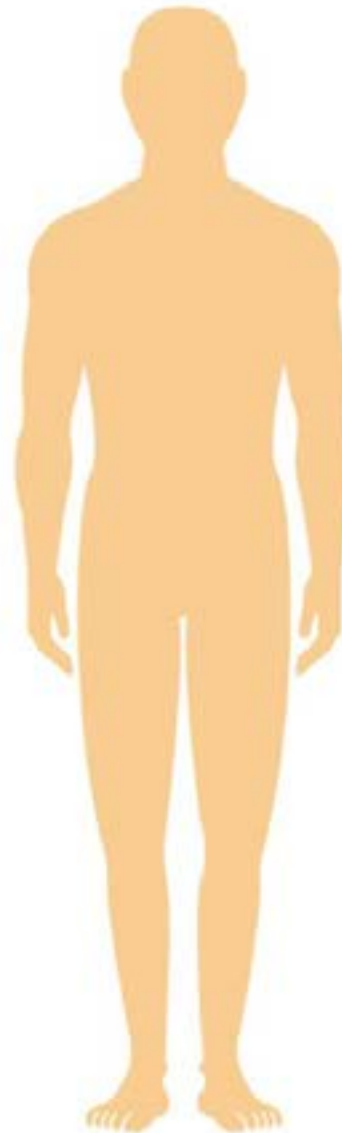
Lungs

Aging leads to impaired pulmonary vascular barrier function due to poor epithelial progenitor cell recovery and extracellular matrix loss, leaving older adults more susceptible to the effects of inhaled particles and toxins



Kidneys / Gut

Increasing age results in a reduction of the body's ability to redirect blood flow from the splanchnic vasculature to surface capillaries for heat dispersal



Brain

Dementia is not only itself a predictor of worse clinical outcome from air pollution exposure, it is itself believed to be worsened by particulate matter inhalation



Skin

Aging is associated with reduction in thermoreceptor density, blunting the body's autoregulatory mechanisms against extreme heat and cold

Older adults have decreased overall sweat production, particularly from the core of the body, reducing evaporative cooling efficiency

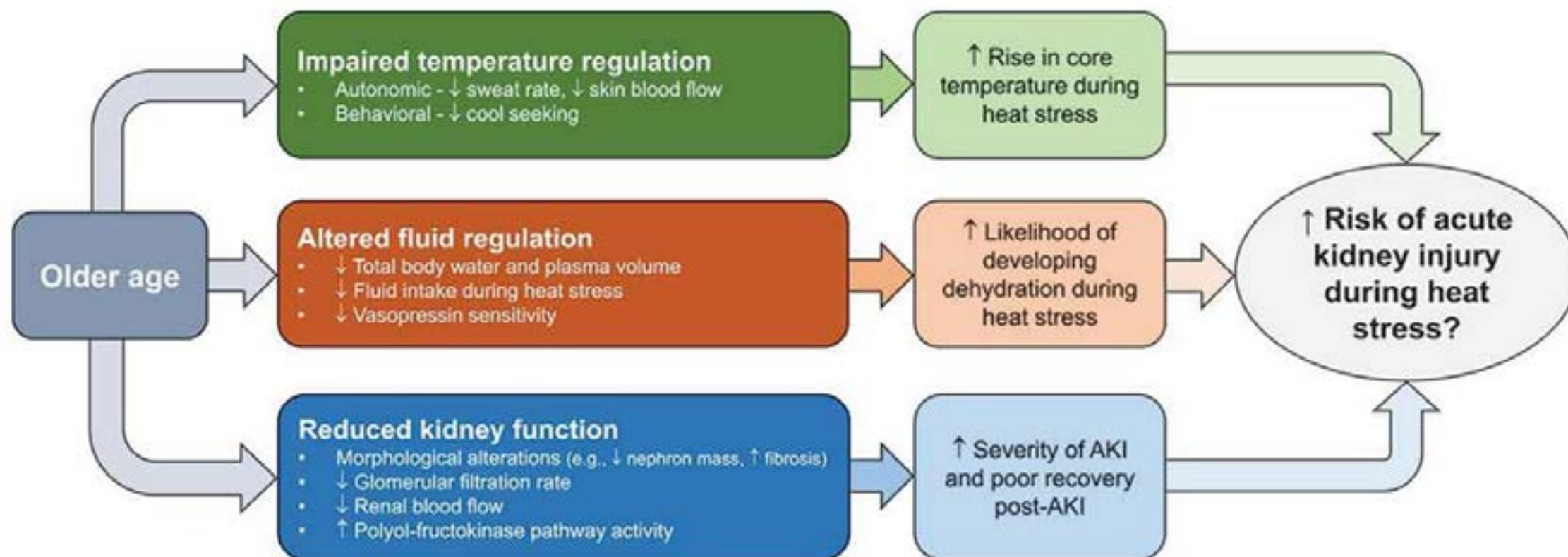


Immune System

Immunosenescence, a phenomenon of weakened innate and adaptive immunity leaves older adults more vulnerable to epidemic infectious disease, less responsive to vaccines, and more susceptible to pro-atherosclerotic autoinflammationthe heart to respond to environmental

Aging-associated physiological changes predisposing older adults to harm from climate change-mediated phenomena

Chang AY et al. Aging Hearts in a Hotter, More Turbulent World: The Impacts of Climate Change on the Cardiovascular Health of Older Adults. *Curr Cardiol Rep.* 2022 Jun;24(6):749-760. doi: 10.1007/s11886-022-01693-6.



Chapman CL et al. Kidney physiology and pathophysiology during heat stress and the modification by exercise, dehydration, heat acclimation and aging. doi: 10.1080/23328940.2020.1826841.

Acute Kidney Injury (AKI)

Acute kidney injury (AKI) is defined as a rapid (hours to days) decrease in kidney function.

AKI represents a wide range of pathophysiological responses of varying severity and causes:

- Decreasing glomerular filtration rate (GFR)
- Increasing concentrations of products of nitrogen metabolism (creatinine, urea)
- Manifest with decreased urine output

Acute Kidney Injury (AKI)

- AKI replaced the older terminology of acute renal failure (ARF)
- AKI better reflects that even small and transient decrements in kidney function can result in deleterious outcomes
- Even rapid recovery (≤ 2 days) from one episode of Stage 1 AKI is associated with a **43% increased risk** of Stage 3 or higher CKD within one year

Acute Kidney Injury (AKI)

Causes of AKI (prerenal):

- The most common type
- Result of the hypoperfusion of the kidneys
- Hypoperfusion increases RSNA, activates the renin-angiotensin-aldosterone system, and stimulates vasopressin release
- Renal blood flow and GFR are reduced
- Ischemic environment is created in the renal vasculature

Acute Kidney Injury (AKI)

Causes of AKI (intrinsic):

- Most commonly caused by ischemia or sepsis
- Primary epithelial cell injury most commonly occurring in the proximal tubule
- S3 segment is particularly susceptible to ischemic injury

Causes of AKI (postrenal or obstructive):

- The least common type
- Occurs due to obstruction of the ureters, bladder outlet, or urethra

Kidney Stone Disease (KSD)

- **Increasing prevalence** in almost all areas of the world
- Prevalence in men has been **stable** during the last decade (11.6% during 2007-2008 and 11.9% during 2017-2018)
- But **has risen in women** (from 6.5% during 2007-2008 to 9.4% during 2017-2018)
- KSD occurs in a wide range of ages, including children, adolescents, and adults
- Patients living in low human development index areas are more prone to develop struvite stones – due to lower access to healthcare

- Combined with heat, high relative humidity is a risk factor
- Higher mean temperatures in the warm season were associated with significant increases in renal admissions for KSD of 15.2% (95% CI: 10.3, 20.4) (Malig et al., 2019)
- The cumulative RR for a daily mean temperature of 30 °C versus 10 °C was between 1.11 (95% CI: 0.73–1.68) and 1.47 (95% CI: 1.00–2.17), the strongest association between KSD and a daily mean temperature was estimated for lags of ≤3 days. (Tasian et al., 2014)

Kidney stone disease

- Increasing prevalence in almost all areas of the world
- Prevalence in men has been stable during the last decade (11.6% during 2007-2008 and 11.9% during 2017-2018)
- But has risen in women (from 6.5% during 2007-2008 to 9.4% during 2017-2018)
- KSD occurs in a wide range of ages, including children, adolescents, and adults

- Patients living in low human development index areas are more prone to develop struvite stones
 - Due to lower access to healthcare
- Heat stress and dehydration also has a role in kidney stone formation
- Increasing temperatures translate into increased admissions through the emergency room
- Heat stress and dehydration predispose to urinary concentration and low urine volumes that increase the risk for stone

Kidney Stone Disease (KSD)

- Heat stress and dehydration also has a role in **kidney stone** formation
 - Increasing temperatures translate into increased admissions through the emergency room
 - Heat stress and dehydration predispose to urinary concentration and low urine volumes that increase the risk for stone
- **Combined with heat, high relative humidity** is a risk factor

Urinary Tract Infection (UTI)

- **Urinary tract infections** are associated to high ambient temperatures
 - In warmer seasons, or during heat waves the number of hospital admissions are increasing
 - The eradication of pathogens from the urinary tract is partially **dependent on voiding frequency and urine flow**
- Lower levels of urine production can hamper the **removal of pathogens**
 - Increasing the potential for a UTI
 - Urinary pathogens are likely to increase in hot weather
- **Combined with decreased hydration and less urination**, the likelihood of developing a UTI may increase

→ Higher mean temperatures in the warm season were associated with significant increases in renal admissions for UTI (change per 10 °F) of 7.3% (95% CI: 5.6–9.1%). (Malig et al., 2019)

Urinary tract infection

→ Urinary tract infections are associated to high ambient temperatures

- In warmer seasons, or during heat waves the number of hospital admissions are increasing
- The eradication of pathogens from the urinary tract is partially dependent on voiding frequency and urine flow
- Lower levels of urine production can hamper the removal of pathogens
 - Increasing the potential for a UTI

→ Urinary pathogens are likely to increase in hot weather

→ Combined with decreased hydration and less urination, the likelihood of developing a UTI may increase

- Elevated RRs of hospitalization during heat were observed for UTI (RR 1.10, 95% CI: 1.04–1.16). (Bobb et al., 2014)
- The odds of a UTI diagnosis increased with higher temperatures in a dose-dependent manner. Relative to months with mean temperatures 5–7.5 °C, admissions in months with average temperatures of 27.5 to 30 °C had 19% greater odds of UTI (95% CI: 17–20%). (Simmering et al., 2018)

Chronic Kidney Disease (CKD)

- Defined by **abnormalities of kidney structure or function**
 - GFR to $<60 \text{ mL/min/1.73 m}^2$
 - Presence of kidney damage persisting for at least three months
- Leading causes:
 - **Diabetes**
 - **Hypertension**
 - Etc.
- Associated risk of end-stage renal disease (ESRD), cardiovascular disease (CVD), and premature death

Chronic Kidney Disease (CKD)

- Increasing incidence and prevalence globally
 - **41.5 million** DALYs (GDB 2019)
 - From 2007-2017, DALYs **increased by 21.5%** (GDB 2017)
 - **1.43 million deaths** directly attributable to CKD (GDB 2019)
- Due to high temperature:
 - 8166 deaths and 221,249 DALYs
 - With a high degree of uncertainty

Chronic Kidney Disease (CKD)

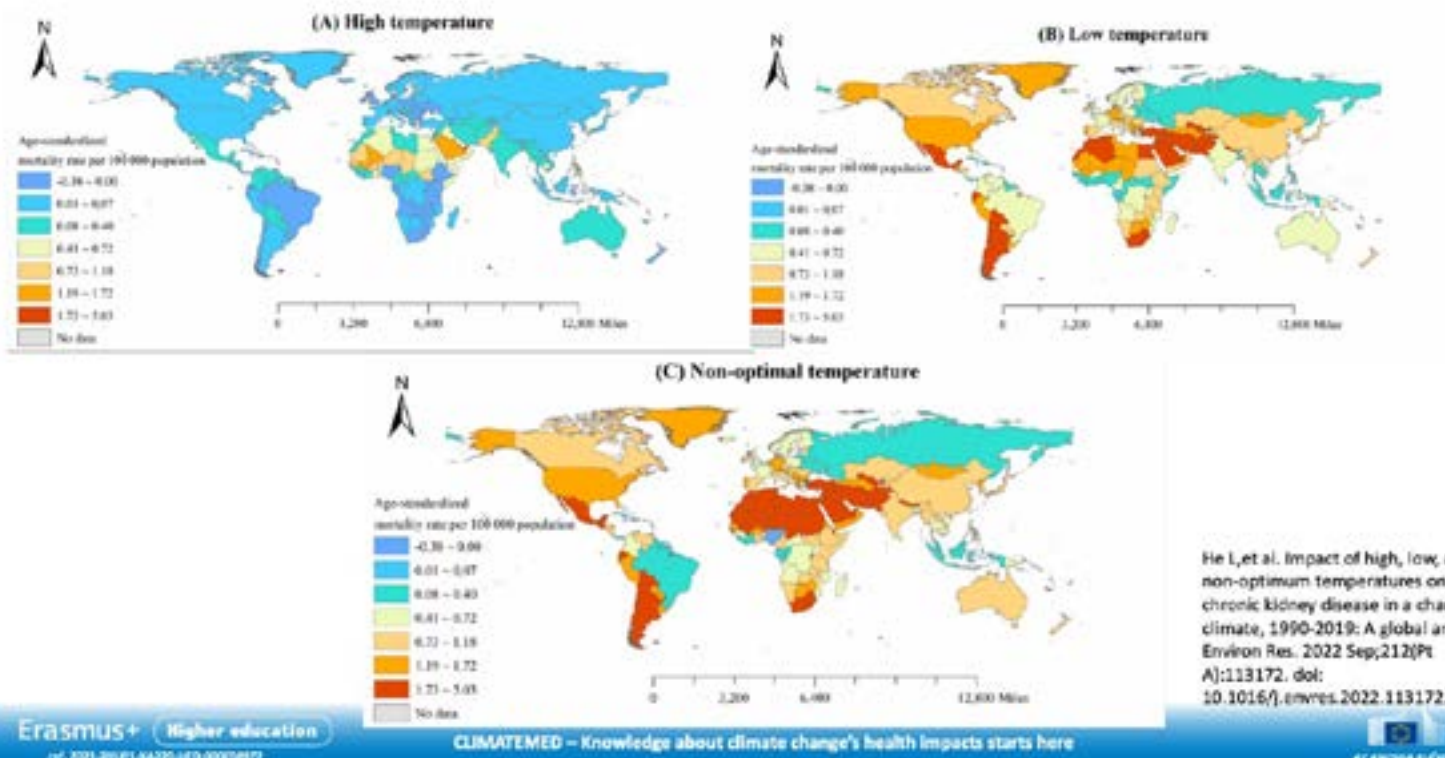
- Development of CKD may result from **repeated AKI** driven by subclinical or clinical heatstroke
- Extreme temperatures are associated with the emergency room visits for CKD
- Lack of studies according to low temperatures
- Would be important:
 - can induce a decrease in the body's immune function and lead to the common cold, the infectious status of which may be related to kidney damage
 - can also induce hypovolemia, atrial dysrhythmias, and cold diuresis which may intensify the kidney burden and cause kidney damage

Chronic Kidney Disease (CKD)

Stages	GFR value ml/min/1.73m2	Classification
I	>90	Normal or High
II	60-89	Slightly decreased
III A	45-59	Mild to moderately decreased
III B	30-44	Moderately to severely decreased
IV	15-29	Severely decreased
V	<15	Kidney failure

Ammirati 2020

Chronic Kidney Disease (CKD)



Chronic kidney disease

- Connection between temperature and CKD
- Findings suggest increases in daily temperature per 1 °C were associated with an increased incidence for CKD (IRR 1.017, 95%CI: 1.001-1.033). (Borg et al., 2017)
- During the July 2007 heat wave in Belgrade there was an increase in mortality related to CKD (200%). (Bogdanovic et al., 2013)
- Development of CKD may result from repeated AKI driven by subclinical or clinical heatstroke
- Extreme temperatures are associated with the emergency room visits for CKD

→ Lack of studies according to low temperatures

→ Would be important:

- can induce a decrease in the body's immune function and lead to the common cold, the infectious status of which may be related to kidney damage
- can also induce hypovolemia, atrial dysrhythmias, and cold diuresis which may intensify the kidney burden and cause kidney damage

Development of chronic kidney disease associated with heat

- Recurrent dehydration can lead to chronic kidney disease due to hyperosmolar hyperglycemia, resulting in vasopressin release and fructose generation through the polyol pathway.
- Vasopressin increases glomerular hydrostatic pressure, increasing the risk of kidney disease progression.
- Fructose, metabolized by fructokinase in the kidney tubule, contributes to tubular damage, oxidative stress, uric acid production, and cytokine release.
- Rehydrating with sugary drinks exacerbates the vasopressin response and uric acid production.

Johnson RJ et al. Metabolic and kidney diseases in the setting of climate change, water shortage, and survival factors

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Development of chronic kidney disease associated with heat

- In addition to these mechanisms, there may be others involved, such as
 - Muscle damage due to strenuous physical exercise with onset of subclinical rhabdomyolysis,
 - Intake of nonsteroidal anti-inflammatory drugs (NSAIDs) and
 - low blood pressure due to volume depletion.
- This would involve the activation of the RAS, which also plays an important role in kidney disease

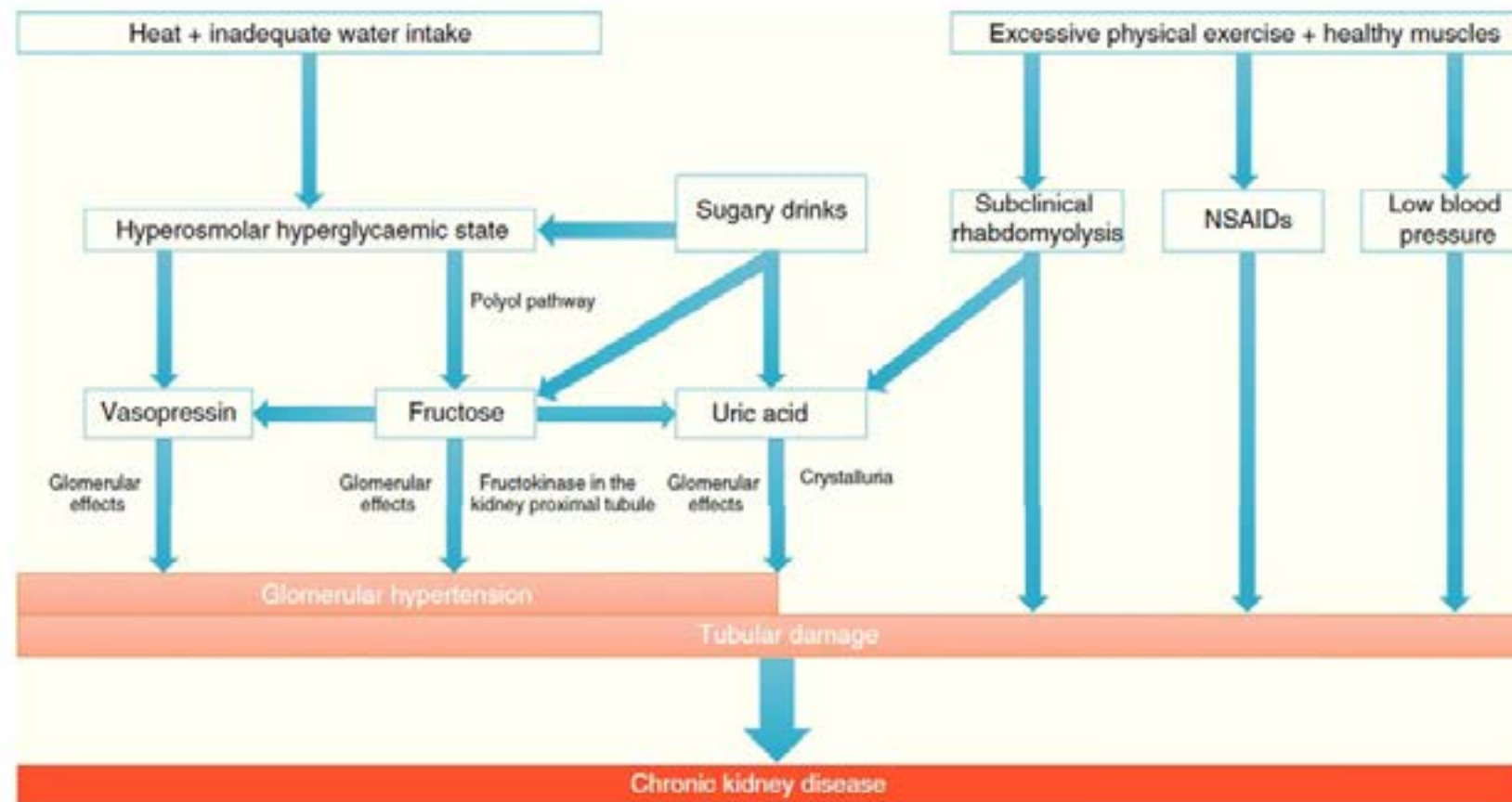
Johnson RJ et al. Metabolic and kidney diseases in the setting of climate change, water shortage, and survival factors

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Development of chronic kidney disease associated with heat



de Lorenzo A, Liaño F. High temperatures and nephrology: The climate change problem. doi: 10.1016/j.nefro.2016.12.008. PMID: 28946962.

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Key points

- Older people are prone to heat-related complications and excess mortality during heat waves
- Physiological neurohormonal changes, structural changes in kidney and body composition and multimorbidity with ageing increases the likelihood of harm during heat waves
- Diagnosis of dehydration is challenging due to the absence of reliable, cost-effective diagnostic tools that are readily available in primary and secondary care
- Timely introduction of anticipatory measures and heat warning systems should be instituted to reduce morbidity and mortality of heat waves in elderly

Brennan M, O'Keeffe ST, Mulkerrin EC. Dehydration and renal failure in older persons during heatwaves-predictable, hard to identify but preventable? Age Ageing. 2019 Sep 1;48(5):615-618. doi: 10.1093/ageing/afz080.

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Take-home messages

- The goal of assessing health risks of heat exposure is to develop targeted interventions to reduce health impacts, since the adverse health effects are largely preventable
 - By encouraging heat stress reduction in the general population and
 - Improved monitoring of kidney function in vulnerable groups through primary health services.
- Additionally, health service providers in emergency departments should be prepared for
 - Increased presentations of kidney diseases such as AKI and urolithiasis during warm seasons.
- Since extreme heat is an important risk factor for kidney disease, clinicians may need to be aware of **potential nephrotoxins** when prescribing medications to patients with pre-existing kidney diseases (e.g. CKD), whose conditions could be exacerbated under extreme heat.

Public health advices

- Adaptive behaviors such as
 - Staying hydrated, using electric fans and/or air conditioning,
 - Staying indoors and avoiding outdoor activities where possible and wearing cool and sun-protective clothing could be recommended.
- Interventions at the population level could include
 - Raising awareness through local media announcements,
 - Introducing heat warning systems,
 - Enhancing the heat response capacity of public health authorities;
 - Providing cool spaces for public use, and
 - Architecture and urban design to better cope with hot environments.

Test your knowledge

- What is the role of the kidneys in thermoregulation of human body?
- What are the most common risk factors for kidney disease?
- Explain how heat stress can increase the risk of acute kidney injury (AKI) in older people.
- What other environmental effect, apart from heat stress, is a risk factor in kidney stone disease (KSD)?
- Describe the reasons why higher ambient temperatures contribute to the likelihood of developing urinary tract infection (UTI).
- List public health advice, in terms of adaptive behaviours and interventions at population level, for the prevention and mitigation of heat stress-induced kidney disease.

Further reading

- Global Climate Change and Human Health: From Science to Practice, by J. Lemery, K. Knowlton, and C. Sorensen. Chapter 3. Publisher: John Wiley, 2021. Print ISBN: 9781119667957, eBook ISBN: 9781119670018.
- Climate Change and Public Health, by B. Levy and J. Patz. Chapter 4B. Publisher: Oxford University Press, 2015. Print ISBN: 9780190202453 eBook ISBN: 9780190202460.

Thank you for you attention!

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Impact of climate change on pregnancy, reproductive outcomes

Learning outcomes

Upon successful completion of the lesson, students will be able to

- know the physiological mechanism of the impact of heat on pregnancy
- know the shorter and longer term consequences of climate change on pregnant women and their newborns
- identify the situations with a high risk of adverse effects of ambient temperature during pregnancy
- give advice to pregnant women about the aspects of prevention
- inform women in reproductive ages about the risk of climate change
- consider the patients' preference in clinical decisions

Changing climate – vulnerable population groups

Climate change is recognized as the biggest global health threat of the twenty-first century



- Elderly
- People with chronic disabilities
- Young children
- **Pregnant women**
- **Newborn babies**

News from the world – CBS NEWS (November 9, 2021)

- **How climate change threatens pregnant women and their fetuses**
- Globally, women are **more vulnerable** to the effects of **climate change** than men, as they make up a majority of the world's poor and depend most on natural resources, according to the U.N.'s Intergovernmental Panel on Climate Change. In the United States, one subgroup of women are particularly at risk: pregnant women.



<https://www.cbsnews.com/news/pregnant-women-fetuses-at-risk-climate-change/>

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News from the world – CNN (January 30, 2019): Climate change could hurt babies' hearts, study says

Heat and pregnancy do not mix. High temps don't just make a pregnant woman uncomfortable, the heat can actually hurt the health of her baby – and with climate change, this will probably become a bigger problem.

A study in Wednesday's Journal of the American Heart Association found that a larger number of babies will probably be born with congenital heart defects between 2025 and 2035 due to their mothers' exposure to higher temperatures, triggered by climate change, while pregnant.

→ <https://edition.cnn.com/2019/01/30/health/climate-change-congenital-heart-defects-study/index.html>

News from the world – The New York Times (June 18, 2020), Independent (June 19, 2020): Climate Change Tied to Pregnancy Risks, Affecting Black Mothers Most

Pregnant women exposed to high temperatures or air pollution are more likely to have children who are premature, underweight or stillborn, and African-American mothers and babies are harmed at a much higher rate than the population at large, according to sweeping new research examining more than 32 million births in the United States.

- <https://www.nytimes.com/2020/06/18/climate/climate-change-pregnancy-study.html>
- <https://www.independent.co.uk/life-style/health-and-families/climate-change-pregnancy-complications-premature-stillborn-black-women-a9575111.html>

News from the world – The Guardian (June 18, 2020): Climate crisis poses serious risks for pregnancy, investigation finds

The investigation, published in the Journal of the American Medical Association, identified 57 studies since 2007 showing a significant association between the two factors and the risk of pre-term birth, low birth weight and stillbirth.

Black mothers were particularly at risk, as were people with asthma.

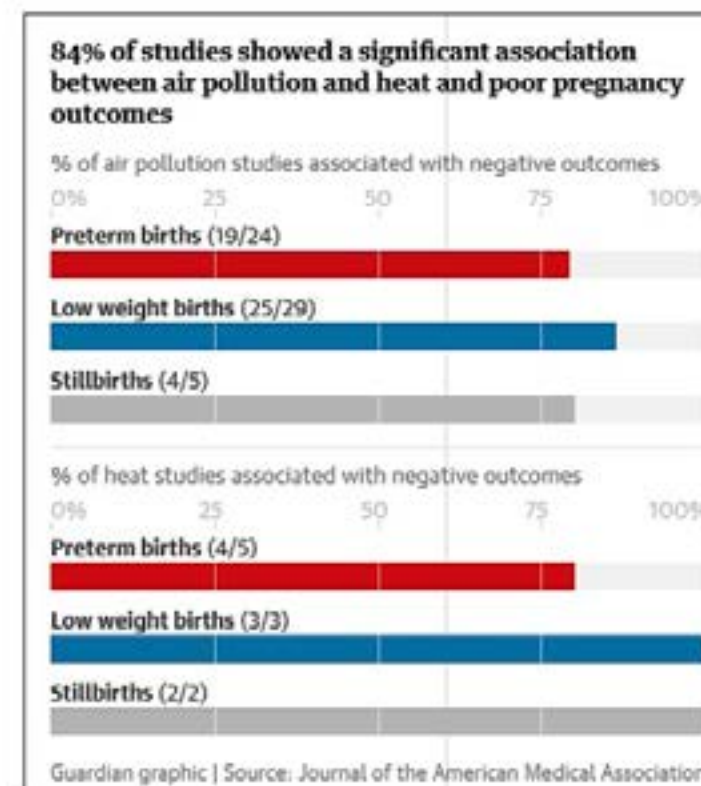
The review analyzed 32 million births tracked across 68 studies. Of those, 84% found air pollution and heat to be risk factors.

Pregnant women on a climate march in Sydney in December last year. Researchers found a strong link between air pollution and heat exposure and the risk of pre-term birth or stillbirth.

→ <https://www.theguardian.com/environment/2020/jun/18/climate-change-air-pollution-investigation-study>

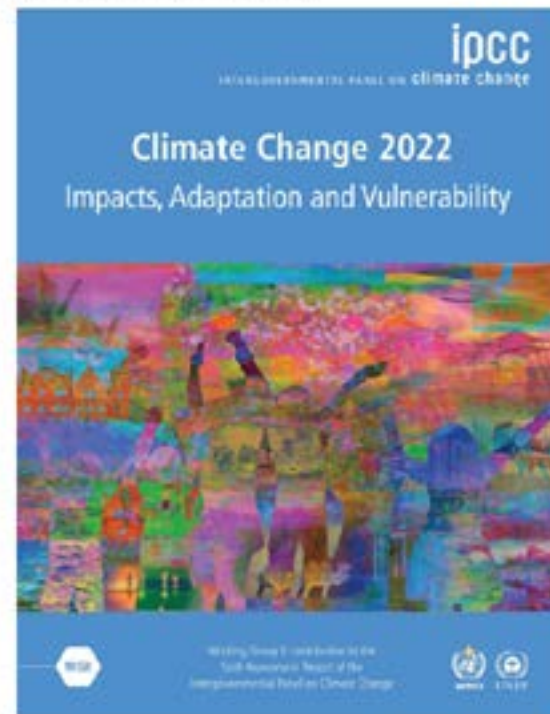
News from the world – The Guardian (June 18, 2020)

- **Climate crisis poses serious risks for pregnancy, investigation finds**



News from the world – PBS NEWS HOUR (March 8, 2022)

A growing body of scientific research cited in the report details the ways in which climate-caused events like heat waves and other natural disasters affect maternal and fetal health.



News from the world – The Indian Express (April 8, 2023): Understanding how heat waves can affect pregnant women: ‘Climate change is only increasing their vulnerability’

According to a 2018 study from National Center for Biotechnology Information, India has the highest burden of climate-sensitive diseases in the world, with maternal and child health being one of the most affected.

→ <https://indianexpress.com/article/lifestyle/health/climate-change-heat-waves-pregnant-women-extreme-temperatures-8509542/>

News from the world – PBS NEWS HOUR (March 8, 2022): How climate change poses unique risks to pregnancy, according to the latest IPCC (Intergovernmental Panel on Climate Change) report

In the latest IPCC report, it says that women and those who are pregnant are more likely to suffer disproportionately in extreme weather events, like heat waves. Why is that?

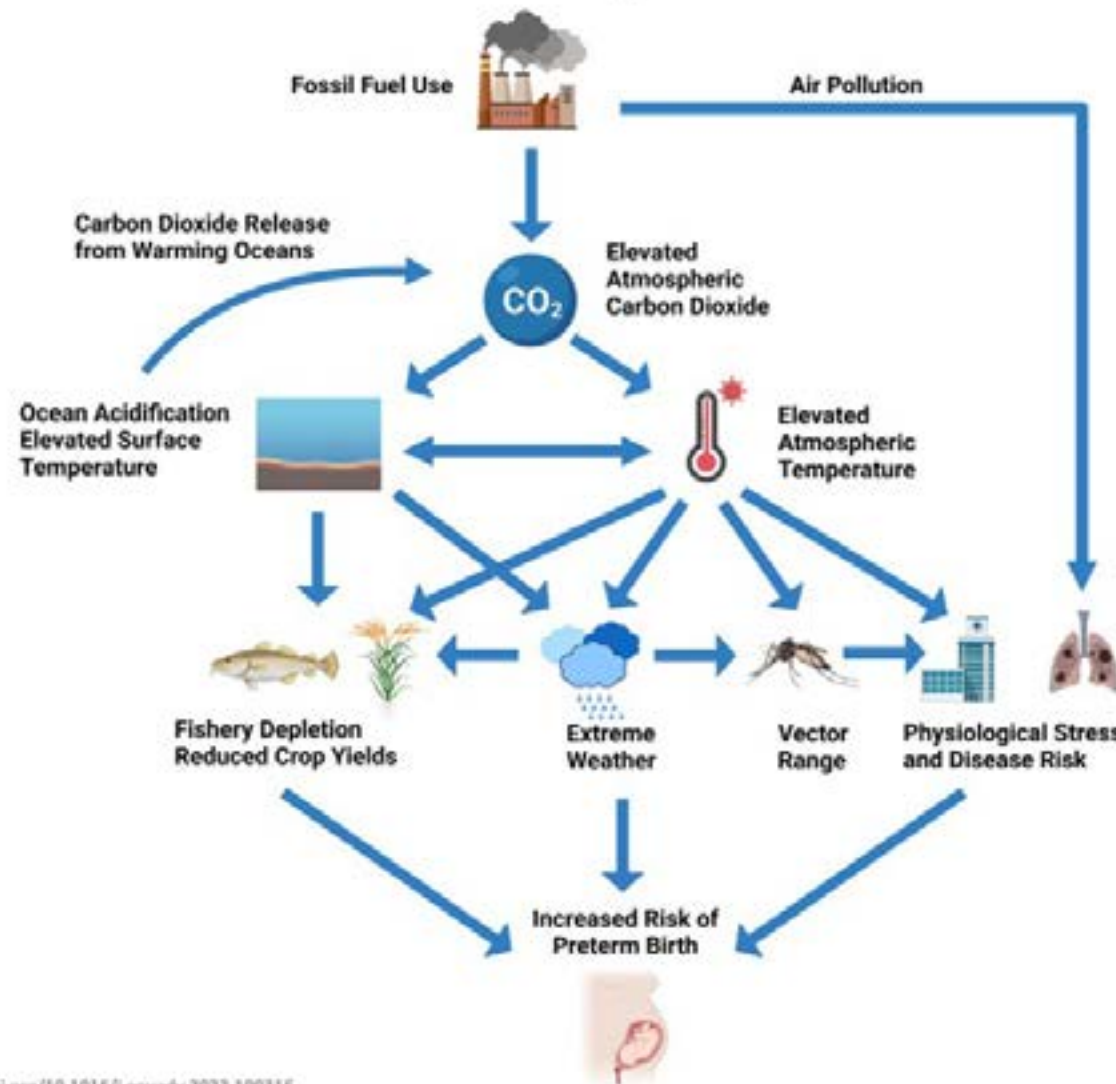
News from the world – The Washington Post (April 11, 2022): Pregnancy becomes a more vulnerable time with climate change

Wildfires, natural disasters, rising heat can lead to poor health outcomes for the expectant and their babies

As scientists study how climate change is affecting human health, pregnant people and their unborn babies are emerging as a vulnerable group.

→ <https://www.washingtonpost.com/health/2022/04/11/climate-change-pregnancy-health-babies/>

Schematic model of interacting direct and indirect effects of climate change on pregnancy outcomes



Extreme weather events in turn, along with elevated temperatures, alter disease vector range and risk of exposure, exert maternal physiological stress and increase disease risk.

Each of these factors, individually and in concert act to increase the risk of preterm birth.

<https://doi.org/10.1016/j.envadv.2022.100316>

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Impacts of climate change on pregnancy outcomes

Directly

- **Natural environment**
 - Wildfire
 - **Extreme heat**
 - Hurricane, flood
 - Drought

Indirectly

- **Natural environment**
 - Air quality
 - Food and water quality, availability
 - Vector, pathogen distribution
- **Social environment**
 - Forced migration (pregnant women are less likely to seek prenatal care, complications)

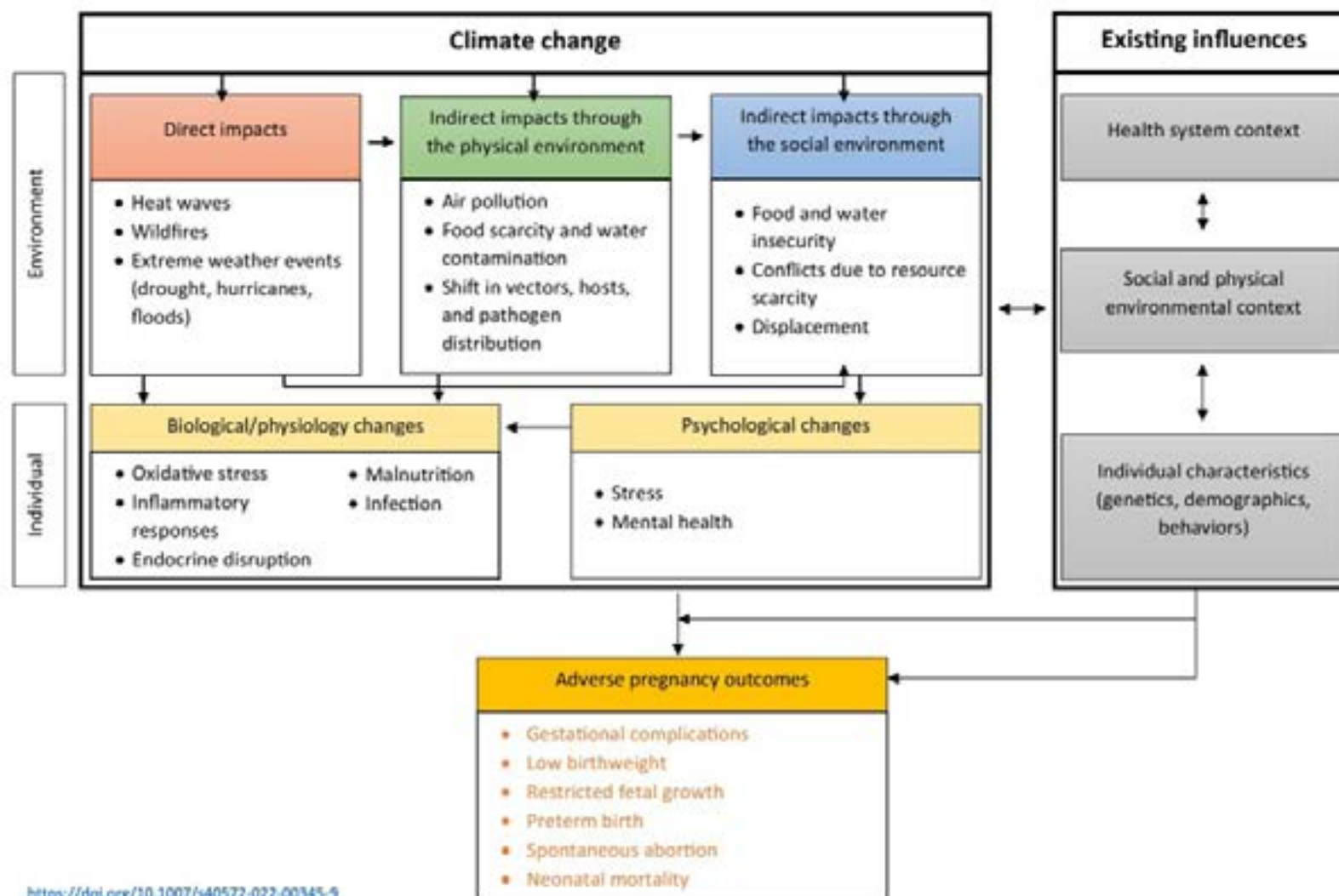
<https://doi.org/10.1007/978-94-007-6034-9>

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Impacts of climate change on pregnancy outcomes



Climate impacts on pregnancy health can be conceptualized to involve

(a) direct impacts via discrete environmental disasters,

(b) indirect impacts through changes in the natural environment, and

(c) indirect impacts through changes in the social environment.

<https://doi.org/10.1007/s10572-022-00345-9>

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Physiological mechanisms of the impact of heat during pregnancy

Thermoregulation
in pregnancy

High ambient
temperature and
intrapartum
maternal fever

Heat exposure and
reduced placental
blood flow

<https://doi.org/10.1007/s00484-022-02301-6>

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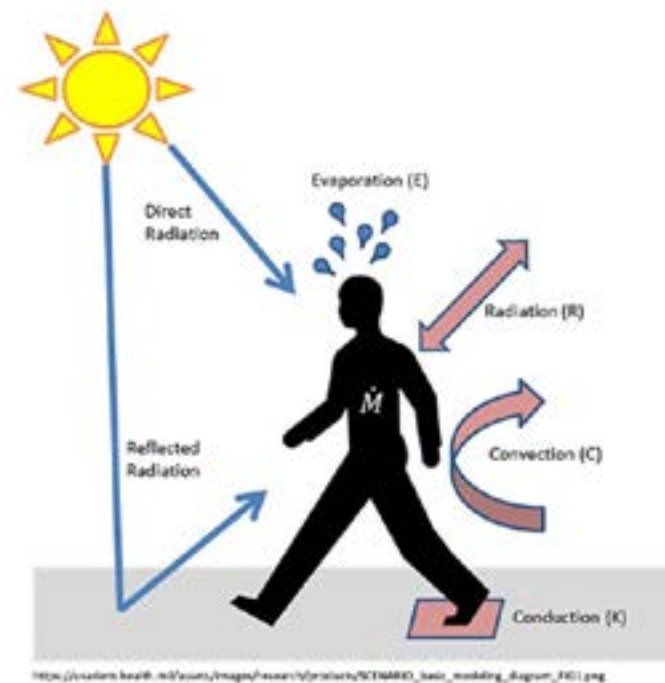
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Physiological mechanisms of the impact of heat during pregnancy

Thermoregulation in pregnancy

Physiological changes of pregnancy include adaptations that affect thermoregulation. Numerous protective adaptive measures exist including a reduction in core temperature, lower sweating threshold, an increase in plasma volume and skin blood flow and an increase in thermal heat capacity due to a rising body mass.

Protective mechanisms could be overwhelmed during exposure to extreme heat resulting in an increased risk of heat strain in pregnancy.



However, whether there are adverse effects of prolonged exercise or physical labour in a hot environment is not yet known and the temperature thresholds at which adverse effects may occur are not well described.

→ | <https://doi.org/10.1007/s00484-022-02301-6>

Pregnancy induces numerous physiological changes in women in addition to changes in body mass. Cardiovascular changes occur gradually throughout pregnancy so that by the third trimester, plasma volume and cardiac output increase by almost 50%.

Physiological changes of pregnancy include adaptations that affect thermoregulation. Numerous protective adaptive measures exist including a reduction in core temperature, lower sweating threshold, an increase in plasma volume and skin blood flow and an increase in thermal heat capacity due to a rising body mass. These enable pregnant women to maintain their core temperature within normal limits.

These protective mechanisms could be overwhelmed during exposure to extreme heat resulting in an increased risk of heat strain in pregnancy.

Fetal core temperature is maintained at approximately 0.5 °C above maternal core temperature.

An increase in maternal core temperature will affect the fetal-maternal temperature gradient and influence the transfer of heat to the fetus.

Studies have shown that short-term exposure to heat through exercise or in a sauna or hot bath does not raise a pregnant woman's temperature over the teratogenic threshold of an increase in 1.5 °C.

Physiological mechanisms of the impact of heat during pregnancy

High ambient temperature and intrapartum maternal fever

There is insufficient evidence to conclude that pregnant women may develop an intrapartum fever as a result of high ambient temperatures during delivery; further studies are needed.



<https://doi.org/10.1007/s00484-022-02301-6>

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Childbirth is a physically strenuous process that normally causes a slight increase in core temperature as a result of endogenous heat production; approximately 0.2 °C over 10 h. Intrapartum maternal fever is defined as a temperature over 38 °C during labour.

There is insufficient evidence to conclude that pregnant women may develop an intrapartum fever as a result of high ambient temperatures during delivery; further studies are needed.

The temperature of the delivery room is appropriate for not only the mother, but also the neonate, who is at risk of developing neonatal hypothermia.

WHO recommend room temperatures between 25 and 28 °C for delivery (WHO 1997), there has been no formal evaluation of the evidence to support this.

The indoor temperature range should reduce heat loss in the infant whilst remaining a comfortable temperature for the labouring woman.

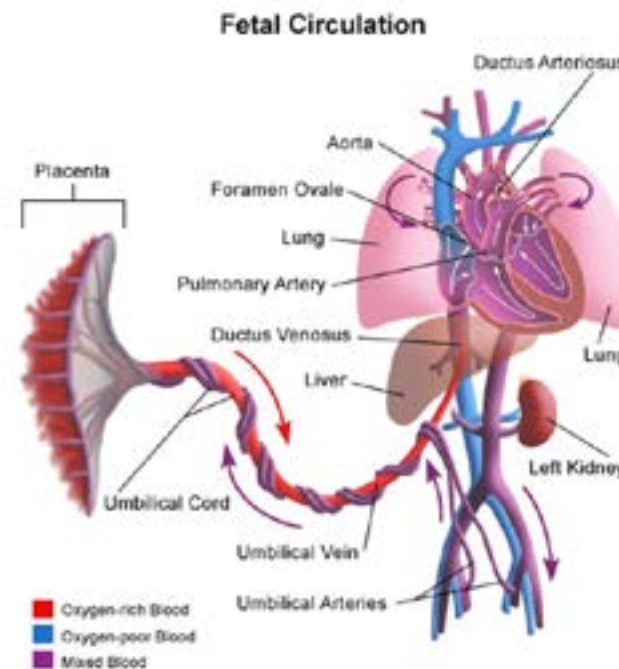
→ | <https://doi.org/10.1007/s00484-022-02301-6>

Physiological mechanisms of the impact of heat during pregnancy

Heat exposure and reduced placental blood flow

The placenta is an end-organ, and it has been hypothesized that during extreme heat exposure, placental perfusion may become reduced to allow increased blood flow to the skin.

A chronic reduction in uteroplacental blood flow can result in foetal growth restriction and low birth weight.



Adults maintain normothermia during heat exposure or exercise by sweating and increasing blood flow to the skin. The resulting rise in skin temperature increases heat loss via convection and radiation and also enhances evaporative capacity of the skin wetted by sweat. Part of this blood flow is redirected from the visceral organs to the skin.

Under extreme heat stress, this results in competition for available cardiac output which may have adverse effects for example, non-pregnant athletes have been shown to risk kidney damage during high workloads in the heat as a result of low renal perfusion rates

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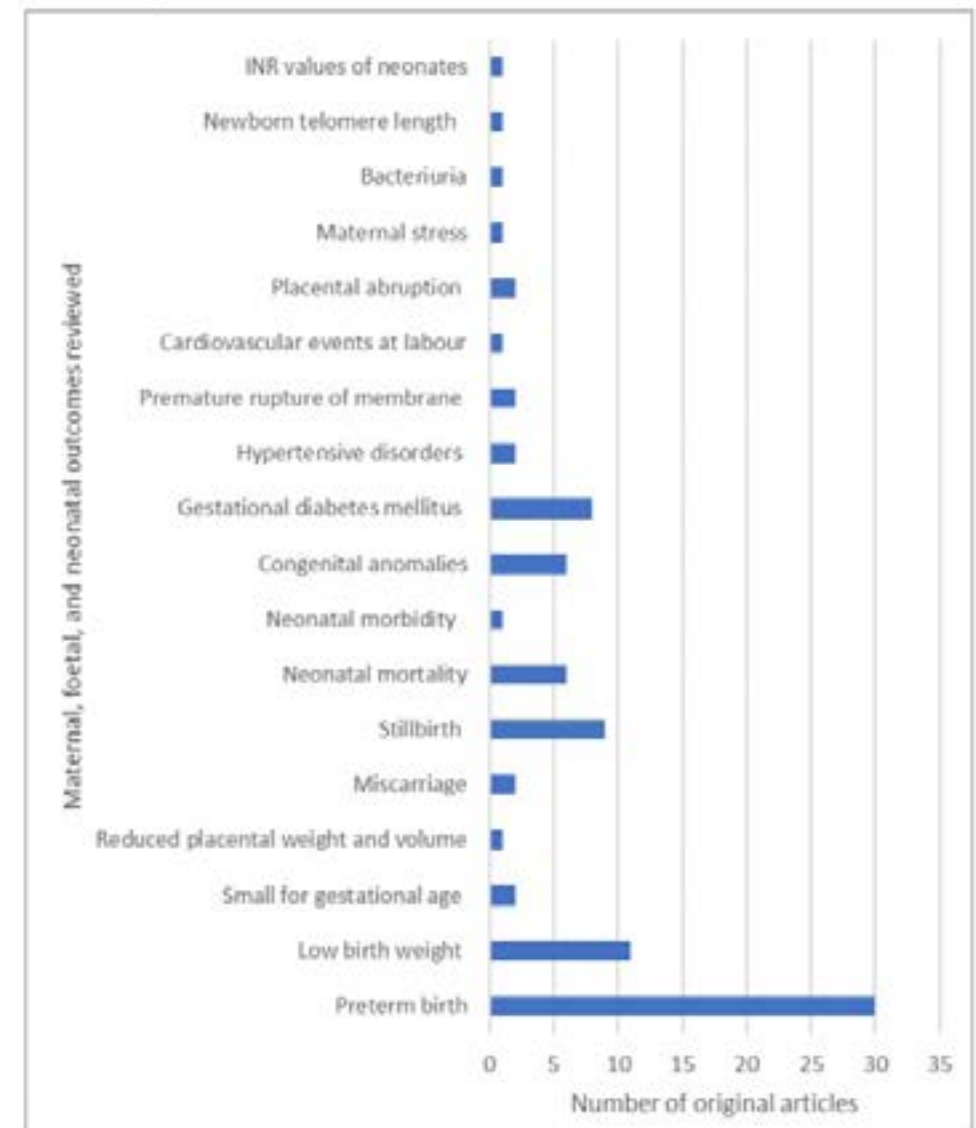
exposure, placental perfusion may become reduced to allow increased blood flow to the skin.

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→ | <https://doi.org/10.1007/s00484-022-02301-6>

Effect of Elevated Ambient Temperature on Maternal, Foetal, and Neonatal Outcomes: A Scoping Review (*Dalugoda et al.*)

This review examined the elevated ambient temperature exposure and the adverse maternal, foetal, and neonatal outcomes regardless of the typical weather patterns to which pregnant women were exposed during their pregnancy.



doi.org/10.3390/ijerph19031771

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This review examined the elevated ambient temperature exposure (e.g., exposure to various high ambient temperatures, heatwave, and extreme temperature events) and

the adverse maternal, foetal, and neonatal outcomes regardless of the typical weather

patterns to which pregnant women were exposed during their pregnancy.

Systematic search from 2005 to 2020

Finally, 75 original articles published between 2015 to 2020 were selected for this scoping review.

→ | doi.org/10.3390/ijerph19031771

Effect of Elevated Ambient Temperature on Maternal, Foetal, and Neonatal Outcomes: A Scoping Review (*Dalugoda et al.*)

PTB is a global epidemic with approximately 15 million global incidences every year.

LBW is associated with prenatal mortality and morbidity and increases the risk of non-communicable diseases later in life.

Stillbirth is a birth following foetal death before labour or during labour, accounting for 2.0 million deaths globally in 2019.

Preterm birth (PTB)

Low birth weight (LBW)

Stillbirth

Neonatal mortality

Neonatal morbidity

Small for gestational age (SGA)

International Normalised Ratio (INR) of neonates

Newborn telomere length

<https://doi.org/10.3390/ijerph19031771>

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→ **Stillbirth** (9 studies)

→ all reported an increased risk for stillbirth with elevated temperatures

PTB (a baby being born before 37 weeks of gestation) is a global epidemic with approximately 15 million global incidences every year. PTB is a leading cause of childhood mortality and morbidity under five years and the direct cause of neonatal mortality (death within 28 days of births).

LBW (live births under 2500 g) is associated with prenatal mortality and morbidity and increases the risk of non-communicable diseases later in life.

Stillbirth is a birth following foetal death before labour or during labour, accounting for 2.0 million deaths globally in 2019.

→ **PTB** (75 studies)

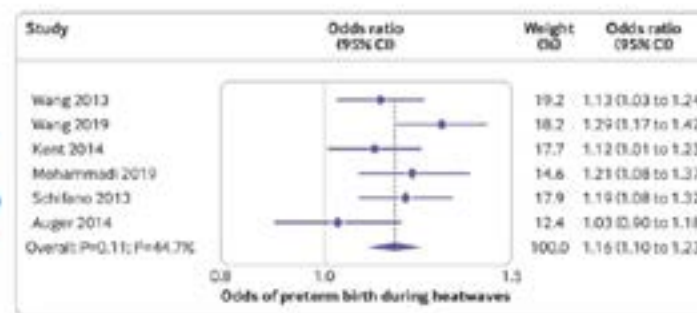
- PTB was the most common adverse outcome
- 23 studies reported that elevated temperatures significantly correlate with an increased risk or rate of preterm birth

→ **LBW** (11 studies)

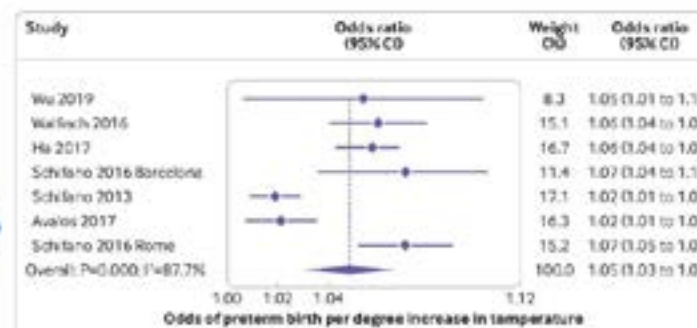
- Five found that elevated temperatures significantly reduce birth weight
- no statistically significant effect of ambient temperature on low birth weight.

Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths

The odds of a preterm birth during a heatwave were 1.16-fold higher than on non-heatwave days.



An average odds of a preterm birth increased by 1.05 for each 1°C increase in temperature.



the pregnancy is recognized, and, even late in pregnancy

Preterm birth analysis

In meta-analysis of six studies, the odds of a preterm birth during a heatwave were 1.16-fold higher than on non-heatwave days (95% confidence interval 1.10 to 1.23; I²=44.7%)

In meta-analysis of seven studies, an average odds of a preterm birth increased by 1.05 for each 1°C increase in temperature (95% confidence interval 1.03 to 1.07) Although there was considerable heterogeneity in estimates (87.7%), all estimates showed significant effects in the same direction.

Birth weight

The median rate of low birth weights in the included studies was 3.0% (interquartile range 1.8-6.4). Of the 16 studies that provided data on the association of temperature with low birth weight, 10 reported that risk increased at higher temperatures, and only one reported the converse (five had null findings). The median of the observed effects of high temperatures on odds of low birth weight was 1.09 (interquartile range 1.04-1.47)

Meta-analysis of 70 studies (13 presented data on more than one review outcome)

Most studies covered impacts of heat exposure on preterm birth (n=47), 28 presented data on birth weight, and eight on stillbirth

Introduction:

Pregnant women included among the groups most vulnerable to heat stress.

Pregnancy raises the vulnerability of women to environmental hazards, including exogenous heat.

The physiological and anatomical changes that occur during pregnancy pose particular challenges to thermoregulation.

Internal heat production rises with fetal and placental metabolism, and with increased body mass and the resulting physical strain.

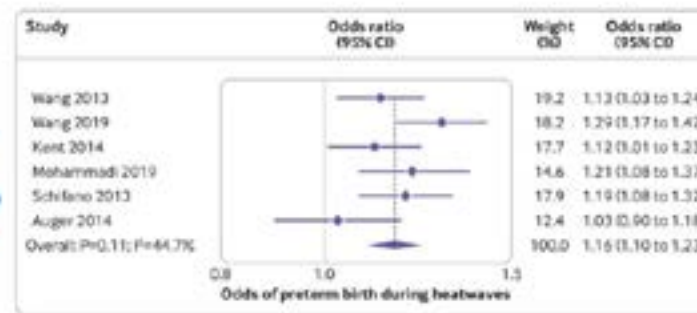
Pregnancy could bring social vulnerabilities to the fore, especially in low and middle income countries

Women continue to perform household chores during pregnancy (e.g., fetching wood and water, and subsistence farming).

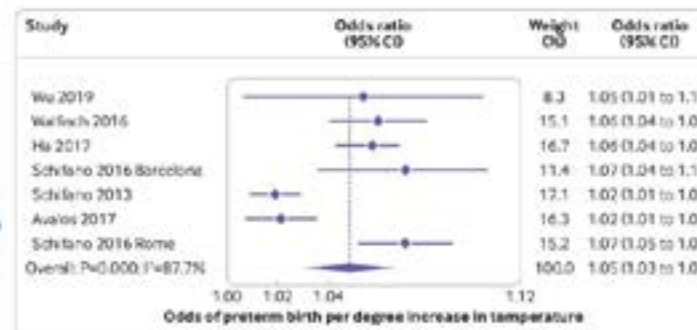
Exposure to high temperatures in agricultural and other outdoor work, could occur before

Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths

The odds of a preterm birth during a heatwave were 1.16-fold higher than on non-heatwave days.



An average odds of a preterm birth increased by 1.05 for each 1°C increase in temperature.



CONCLUSIONS OF THIS STUDY

This systematic review collates evidence that exposure to high temperature is associated with an increase in adverse pregnancy outcomes.

Associations of heat with preterm birth and stillbirth appear to be stronger and more consistent than those with birth weight.

Associations between temperature and birth outcomes appear especially pronounced among women in low socioeconomic groups. This suggests that pregnant women in low and middle income countries could be at particular risk from heat exposure.

The study shows the potential effects on health of continued increases in mean global temperatures and of the frequency of heatwaves.

Of the 19 studies reporting birth weight as a continuous variable, 12 noted decreases in birth weight at higher temperatures, including two where the direction of effect varied by trimester, three studies had non-significant findings, and four noted that weight increased at higher temperatures

The impacts of temperature on weight were small, with most studies reporting changes of under 10 g per change in degree, or under 20 g when comparing high and low temperatures.

Stillbirth

The median stillbirth rate was 6.2 per 1000 births (interquartile range 4.4-6.4). All eight included studies detected an increase in stillbirths at higher temperatures. In most cases, associations between temperature and stillbirth were most pronounced in the last week or month of pregnancy.

In meta-analysis, stillbirths increased by 1.05 (95% confidence interval 1.01 to 1.08) per 1°C rise in temperature, by 1.24-fold (1.12 to 1.36) at lags measured on individual days in the last week of pregnancy, and by 3.39-fold (2.33 to 4.96) when temperature effects were examined over a trimester or the whole pregnancy period.

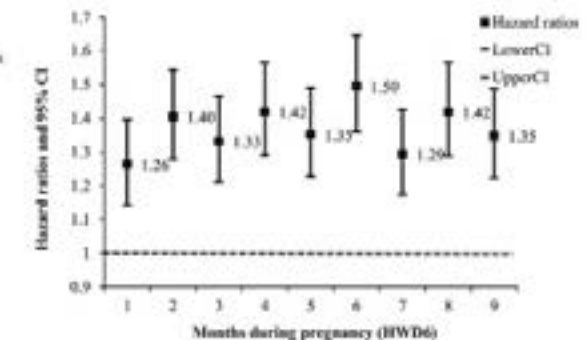
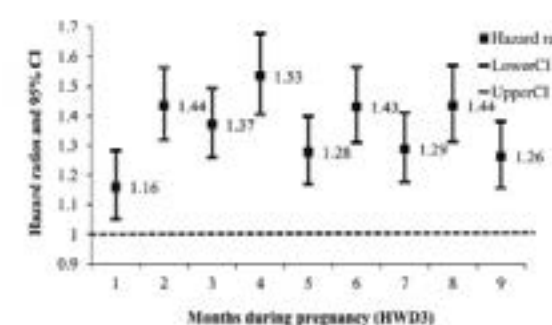
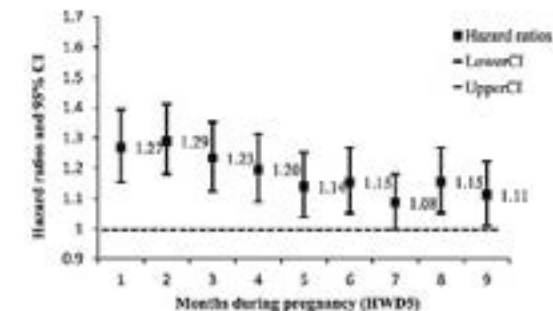
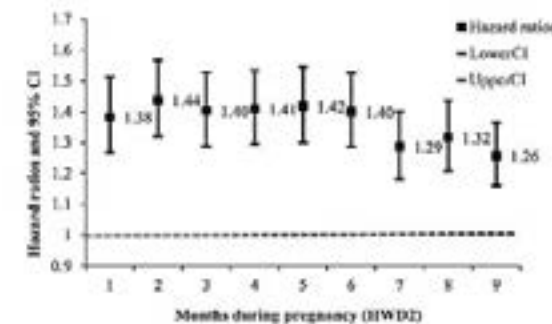
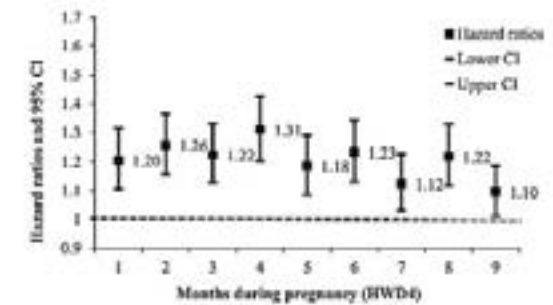
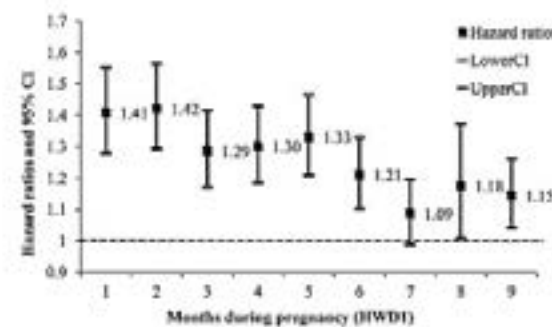
→ doi.org/10.1136/bmj.m3811

Exposure to Heat Wave During Pregnancy and Adverse Birth Outcomes

Hazard ratios (HRs) of spontaneous preterm birth associated with heat wave exposure in different gestational months in Brisbane, Australia

The adjusted HRs of preterm birth increase slightly but fluctuate moderately across different months.

Using HWD1, the adjusted HRs of preterm birth vary in different gestational months with the highest HR in the second gestational month and the lowest HR in the seventh gestational month.



doi:10.1097/EDE.0000000000000995

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Exposure to Heat Wave During Pregnancy and Adverse Birth Outcomes

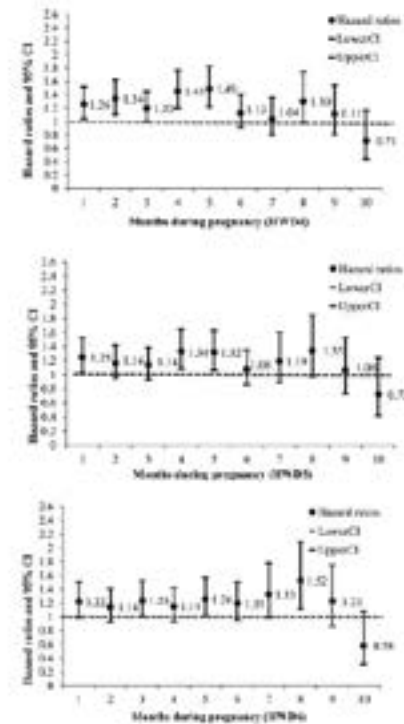
HRs of stillbirth associated with heat wave exposure during different gestational months in Brisbane, Australia

For most heat wave definitions, heat wave exposure in earlier gestational months, which was between months 1 and 6, was associated with higher risk of stillbirth.

The risks of stillbirth fell considerably in the seventh month compared with the sixth month and increased moderately in the eighth month.

Meanwhile, declined trends were also observed for heat wave exposure in the ninth and tenth gestational months.

For HWD6, the highest risk of stillbirth occurred in the eighth gestational month.



all gestational months for most heat wave definitions.

For instance, using HWD1, the adjusted HRs of preterm birth vary in different gestational months with the highest HR in the second gestational month (HR = 1.42; 95% CI = 1.29, 1.56) and the lowest HR in the seventh gestational month (HR = 1.09; 95% CI = 0.99, 1.20).

AIM: to examine the effects of heat wave exposure in different gestational months on the risk of preterm birth and stillbirth.

SAMPLE: There were 277,133 singleton births including 17,368 preterm births and 1684 stillbirths during 2000–2010 in Brisbane. Among them, 7691 preterm births and 705 stillbirths occurred in warm months (November–March in Brisbane).

RESULTS: Six heat wave definitions were used in this study.

For most heat wave definitions, the adjusted hazard ratios (HRs) of preterm birth varied by different gestational months and ranged from

1.08 (HR = 1.08; 95% CI = 1.00, 1.18) to 1.53 (HR = 1.53; 95% CI = 1.41, 1.68).

Heat wave exposure in early pregnancy was more likely to increase the risk of stillbirth compared with heat wave exposure in late pregnancy.

There were relationships between preterm birth and heat wave exposure in all months of pregnancy based on most heat wave definitions. No specifically high period of susceptibility during pregnancy for preterm birth associated with heat wave exposure was found.

There is a positive relationships between preterm birth and heat wave exposure in

Extreme heat, preterm birth, and stillbirth: A global analysis across lower-middle income countries

AIMS

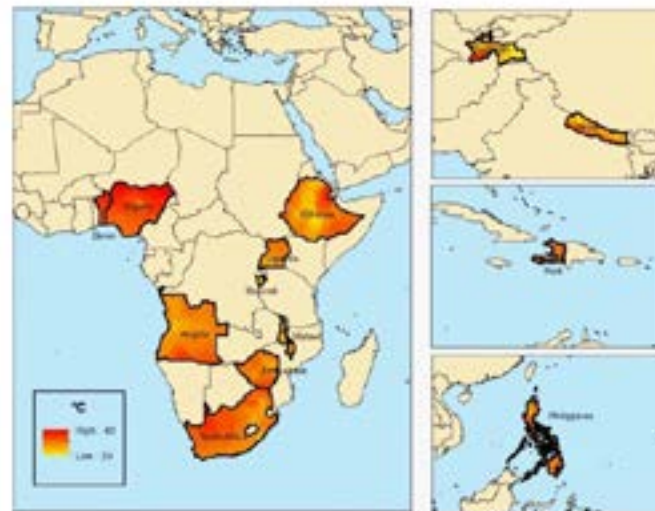
Examining how exposure to extreme heat affects adverse birth outcomes in 14 lower-middle income countries with some of the highest rates of preterm and stillbirths.

METHODS

The selected countries participated in the most recent Demographic and Health Survey, which was completed between 2014 and 2018 and contained data for at least one of the outcomes of interest (preterm birth or stillbirth).

RESULTS

A consistent and positive association between extreme heat beyond specific thresholds and risk of preterm birth and stillbirth in lower-middle income countries.



doi.org/10.1016/j.envint.2021.106902

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ref. 10101-2019-1-UK01-KA201-HE0-00004972

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observed three to five days after the extreme temperature.

→ doi.org/10.1016/j.envint.2021.106902

AIM: to examine how exposure to extreme heat affects adverse birth outcomes in 14 lower-middle income countries (LMICS) with some of the highest rates of preterm and stillbirths.

METHODS: The selected countries participated in the most recent Demographic and Health Survey (DHS), which was completed between 2014 and 2018 and contained data for at least one of the outcomes of interest (preterm birth or stillbirth).

All women aged 15 to 49 in these countries were considered for the analysis if they answered questions about their birth histories, household demographics, and health practices.

For this study two data sources were linked: the DHS and global gridded temperature.

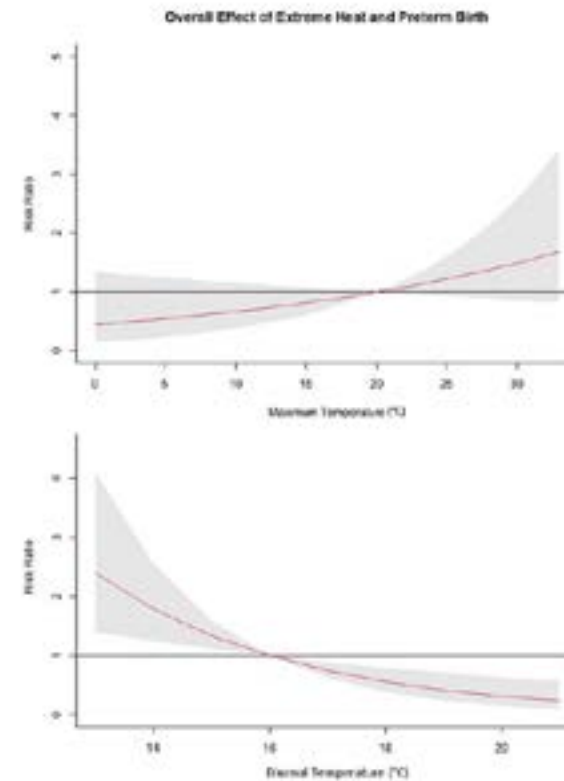
RESULTS: In total, 103,535 births were included in this study across the 14 countries. There were 5882 preterm birth cases and 1210 stillbirth cases. A consistent and positive association between extreme heat beyond specific thresholds and risk of preterm birth and stillbirth in LMICs.

The findings from the lagged analyses suggest there are different critical windows of susceptibility to preterm birth and stillbirth due to heat exposure. An immediate effect of high temperatures is observed for preterm birth. In contrast, increased risk of stillbirth is

*Overall effect of distributed lag nonlinear case-crossover curve with reference at 20 °C for maximum temperature and diurnal temperature range with reference at 16 °C and **preterm birth**.*

There was an increased risk of preterm birth among women who were exposed to extreme heat within the seven days before giving birth.

An elevated risk of preterm birth was also identified among pregnant women who experienced diurnal temperature ranges of less than 16 °C.



doi.org/10.1016/j.envint.2021.106902

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Overall, there was an increased risk of preterm birth among women who were exposed to extreme heat within the seven days before giving birth. The distributed lag nonlinear model identified a range of temperatures that increased the risk of preterm birth.

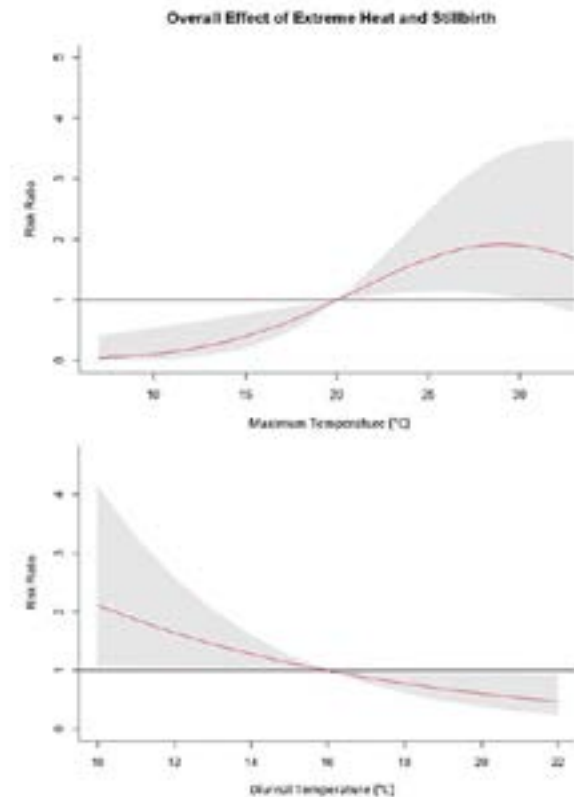
An elevated risk of preterm birth was also identified among pregnant women who experienced diurnal temperature ranges (i.e., difference between daily maximum and minimum temperatures) of less than 16 °C.

→ | doi.org/10.1016/j.envint.2021.106902

Overall effect of distributed lag nonlinear case-crossover curve with reference at 20 °C for maximum temperature and diurnal temperature range with reference at 16 °C and stillbirth.

For stillbirth, the results indicate an increased risk among pregnant women who experienced hot temperatures within the seven days prior to giving birth.

An increase in stillbirth was observed for pregnant women who experienced a day within the week prior to giving birth with smaller diurnal temperature ranges. The window of elevated risk was found to be for diurnal temperature range less than 16 °C.



doi.org/10.1016/j.envint.2021.106902

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For stillbirth, the results indicate an increased risk among pregnant women who experienced hot temperatures within the seven days prior to giving birth. The hot temperature-stillbirth nonlinear association showed a window of temperatures, 20–30 °C, where a pregnant woman is more susceptible to stillbirths as compared to the risk of stillbirth at the identified reference temperature of 20 °C. A decreased risk of stillbirth was observed for temperatures less than the reference temperature

An increase in stillbirth was observed for pregnant women who experienced a day within the week prior to giving birth with smaller diurnal temperature ranges (RR = 2.1, 95% CI 1.01, 4.02). The window of elevated risk was found to be for diurnal temperature range less than 16 °C.

→ | doi.org/10.1016/j.envint.2021.106902

Elevated Ambient Temperature – Associated Adverse Neonatal Outcomes

- **Neonatal mortality** (inconsistent findings):
 - Two studies: elevated temperatures ~ increased mortality
 - Two studies: elevated temperatures ~ decreased mortality
 - Two studies: no impact
- **Neonatal morbidity** (one study):
 - Heatwaves ~ increased risk of foetal distress, ventilator-associated breathing for more than 30 min, meconium aspiration syndrome
- **SGA** (limited research, inconsistent findings):
 - One study: increased risk of term SGA
 - One study: no association
- **INR of neonates** (one study):
 - Seasonal variations: higher INR in summer vs. winter
 - Outdoor temperature significantly influenced the INR values (positive correlation)
- **Newborn Telomere Length** (one study):
 - Higher temperature (>19.5 C) was associated with shorter cord blood telomere length

Preterm birth (PTB)

Low birth weight (LBW)

Stillbirth

Neonatal mortality

Neonatal morbidity

Small for gestational age (SGA)

International Normalised Ratio (INR) of neonates

Newborn Telomere Length

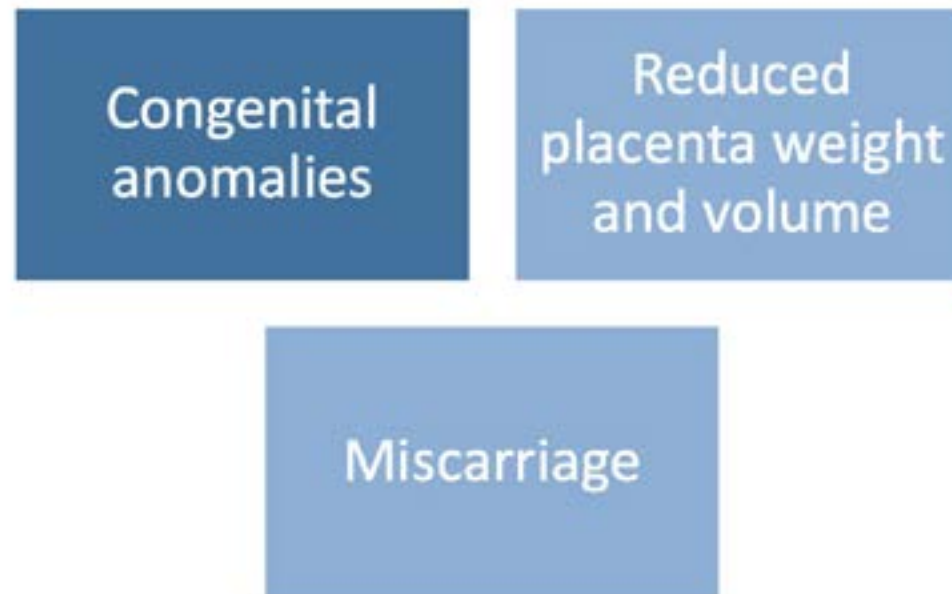
<https://doi.org/10.3390/ijerph19031771>

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Elevated Ambient Temperature - Associated Adverse Foetal Outcomes



Study 2: a possible association between elevated temperature and miscarriages, but the results were not statistically significant

→ | <https://doi.org/10.3390/ijerph19031771>

Congenital Anomalies (six studies, inconsistent findings)

association between high temperatures and congenital heart defects (CHD)

maternal exposure to a maximum daily temperature of 30 C was significantly associated with an increased risk of multiple and noncritical congenital heart defects

the risk for noncritical CHD further increased with extreme summer heat exposures

neural tube defects show a weak positive association with high temperatures (>30 C) - elevated temperature may be a risk factor for neural tube defects

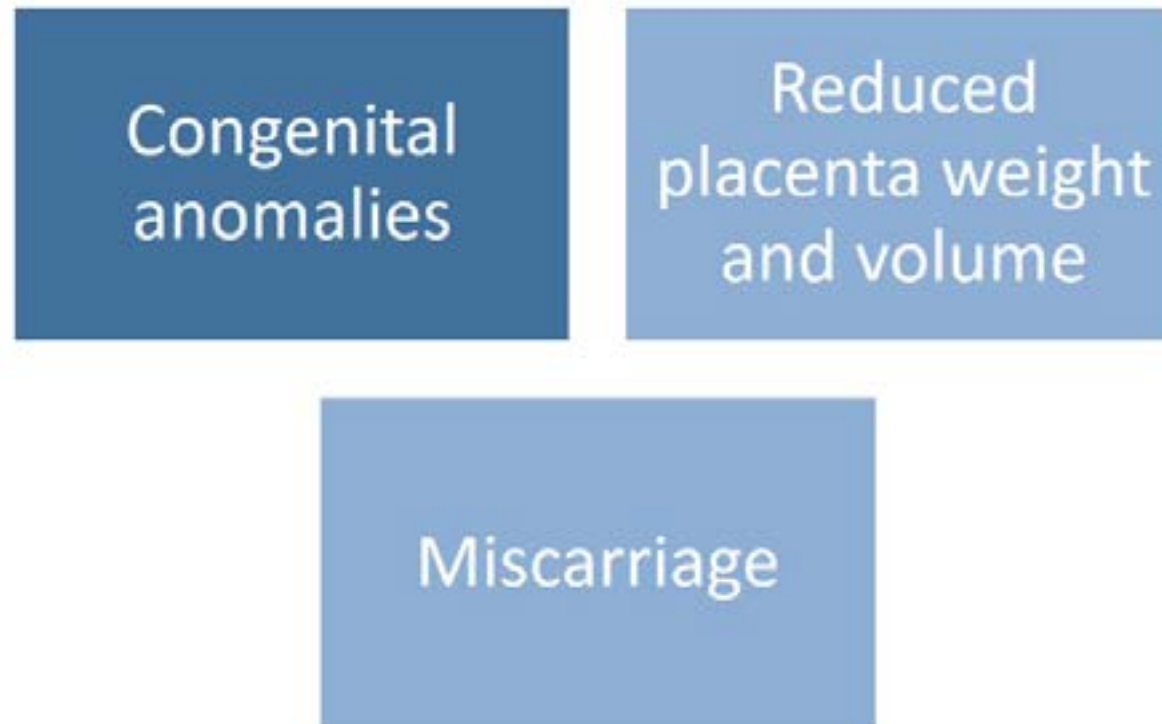
Reduced Placental Weight and Volume (one study)


negative association between high temperatures and placental weight and volume and a positive association with placental efficiency

Miscarriage (two studies, inconsistent findings)

Study 1: exposure to moderately high temperatures (23.1 C) during the last two months before hospitalisation increased the risk of miscarriage (OR 1.243) before 28 weeks gestation


Elevated Ambient Temperature - Associated Adverse Foetal Outcomes



CONGENITAL HEART DEFECTS 

CONGENITAL HEART DEFECTS (CHD)
are present **AT BIRTH** and occur when a baby's **HEART DOES NOT DEVELOP OR WORK THE WAY IT SHOULD.**

CHD IS THE MOST COMMON TYPE of birth defect.
1 IN 100 BABIES are born with a heart defect each year in the U.S.
OVER 1 MILLION ADULTS are living with congenital heart defects.

THE GOOD NEWS IS...

... **9 OUT OF 10** children born with a heart defect now **SURVIVE INTO ADULTHOOD** thanks to medical advances.

LONG-TERM CHD CHALLENGES

- Heart Valve Problems
- Pulmonary Hypertension
- Abnormal Heart Rhythms (arrhythmias)
- Anxiety and Depression
- Heart Infections (endocarditis)
- Heart Failure
- Need for Repeat Surgeries or Procedures
- Stroke

How to LIVE WELL with CHD

- Understand your heart defect and ask questions
- Ask if it is safe for you to get pregnant
- Keep all follow-up medical appointments - even if you are feeling well
- Meet with a heart (or CHD) specialist when reaching adulthood
- Maintain regular dental checkups
- Seek emotional support as needed
- Know your health insurance options

For more information, visit [CardioSmart.org/CHD](https://www.CardioSmart.org/CHD)

<https://doi.org/10.3390/ijerph19031771>

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Elevated Ambient Temperature - Associated Adverse Maternal Outcomes



the role of placental abruption plays role in the association between elevated temperature and stillbirth

Maternal Stress (one study)

extreme temperature increases maternal stress during pregnancy

Cardiovascular Risk at Labour (one study)

exposure to 1 C increases in temperature during the last week of pregnancy increases the cardiovascular risk by 7% and that the risk was more evident on days closer to delivery.

→ <https://doi.org/10.3390/ijerph19031771>

Hypertensive Disorders (two studies)

maternal exposure to heatwaves and high average temperature increased the risk of preeclampsia, eclampsia, and gestational hypertension

Bacteriuria (one study)

increased maternal risk with significant bacteriuria, with high ambient monthly temperature

Premature Rupture of Membrane (PROM)(two studies)

PROM occurs due to the natural weakening of the foetal membrane, which triggers the foetal membrane's rupture without labour onset

elevated temperatures are associated with a higher risk of PROM

Placental Abruption (two studies)

high risk for placental abruption associated with high-temperature exposures during the pregnancy period

elevated temperature (>30 C) in warm seasons increases the risk of placental abruption by 7%,

Elevated Ambient Temperature - Associated Adverse Maternal Outcomes

Increased prevalence of GDM, the likelihood of GDM diagnosis, and serum glucose levels with elevated temperatures, especially in the summer season.

Each 10 °C increase in mean 30-day temperature was associated with a 6-9% relative increase in the risk of GDM.



Gestational diabetes (GDM) 8 studies

→ <https://doi.org/10.3390/ijerph19031771>

Canadian cohort study that observed 555,911 births among 396,828 pregnant women over 12 years found a direct relationship between mean 30-day outdoor air temperature (>24 °C) before the routine GDM screening at 27 weeks of gestation and the likelihood of being diagnosed with GDM.

Each 10 °C increase in mean 30-day temperature was associated with a 6-9% relative increase in the risk of GDM.

Higher serum glucose levels on the day of the oral glucose tolerance test were reported in summer.

Prenatal ambient temperature and risk for schizophrenia

Significant positive correlation coefficients were demonstrated between mean monthly temperature and conception rate for those developing schizophrenia, suggesting that higher temperatures at conception, which in the U.S. occur in summer, were associated with more conceptions of offspring who developed schizophrenia.



→ <https://doi.org/10.1016/j.schres.2021.09.020>

AIM

Testing the hypothesis that early pregnancy ambient heat associates with greater psychiatric disorders including schizophrenia and congenital malformations.

Twenty-two studies met criteria and one was added from a reference list (n = 23). Of these, schizophrenia (n = 5), anorexia nervosa (n = 3) and congenital cardiovascular malformations (n = 6) studies were the most common. Each of these categories showed some evidence of association with an early pregnancy maternal ambient heat exposure effect, with other evidence for a late pregnancy cold effect.

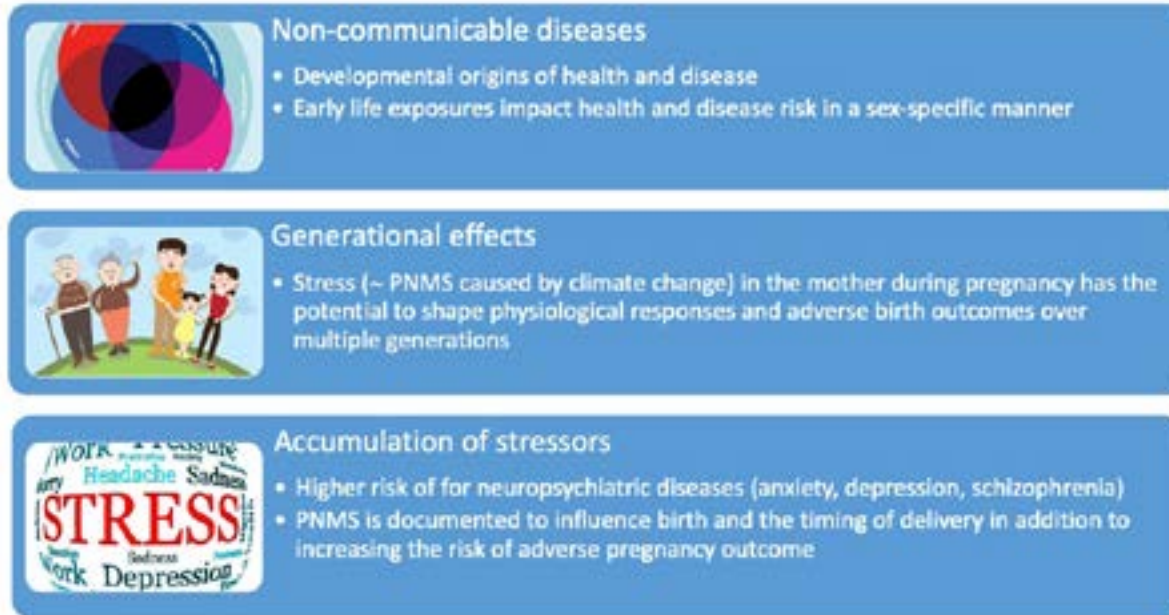
RESULTS

Of the five studies focusing on schizophrenia, only one reported a link to prior summer mean temperature

Significant positive correlation coefficients were demonstrated between mean monthly temperature and conception rate for those developing schizophrenia, suggesting that higher temperatures at conception were associated with more conceptions of offspring who developed schizophrenia.

Some evidence supports a role for early pregnancy maternal exposure to extreme ambient heat in the development of psychiatric disorders, but large-scale, prospective cohort data on individual births is essential.

Prenatal maternal stress (PNMS)



<https://doi.org/10.12688/f1000research.27157.1>

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ref. 2021-2HUE1-KA220-HED-00004972

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Climate change is a major stressor causing poor pregnancy outcomes and child development

This review discusses the main health challenges faced by mothers, fathers, and their children during the climate crisis, focusing on mental health as a causal factor. Exploration of this topic includes the role of prenatal maternal and paternal stresses, allostatic load, and the effect of degradation of the environment and ecosystems on individuals.

This review explores the topic of prenatal maternal stress (PNMS) and paternal stress, allostatic load, and the effect of degradation of the environment on individuals. These will be examined in relation to adverse pregnancy outcomes and altered developmental

trajectories of children. This exploration will reveal a public health paradox whereby many of the global gains made in recent decades in maternal-child health will be nullified by the losses due to climate change.

Pregnant women and their developing children are one of the groups most at risk of the effects of the climate crisis

The estimation is that 25,000 infants per year between 1969 and 1988 were born earlier than normal (39–40 weeks' gestation) as a result of heat exposure, with a total loss of 150,000 gestational days per year. Without intervention, the estimate is that by the end of the century there will be an additional loss of 250,000 days of gestation per year¹⁰. The World Health

Organization estimates that 88% of the burden of disease attributable to climate change occurs in children younger than 5 years.

Effects of the climate crisis on mental health

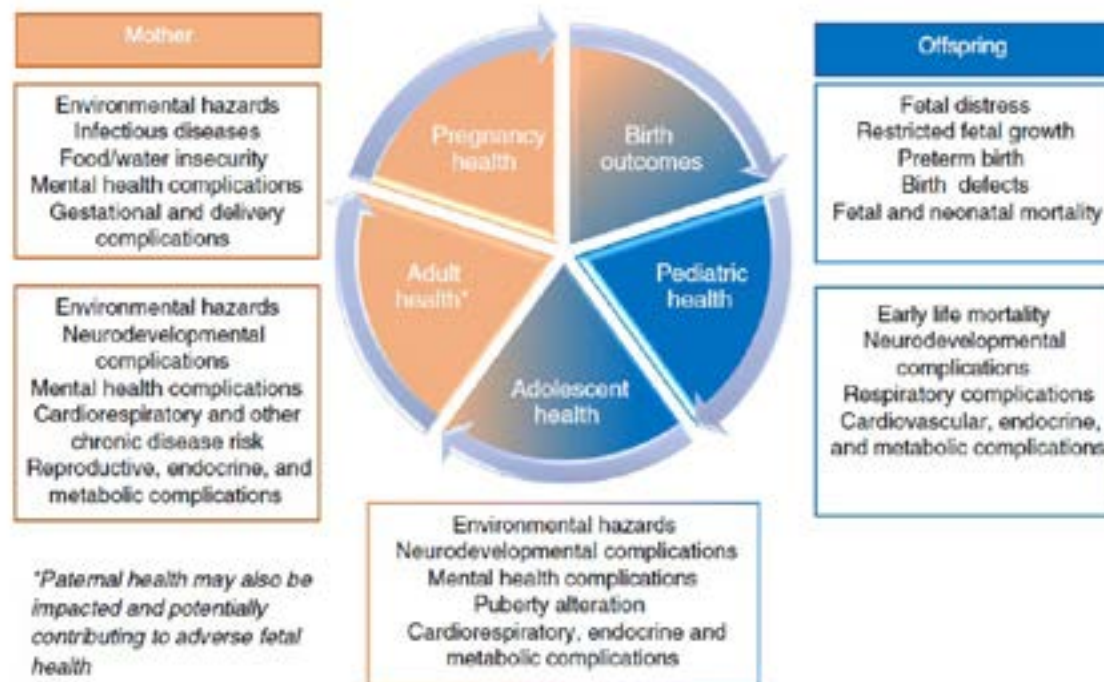
Berry in 2010 pointed out that climate change may directly affect mental health through exposure of its victims to trauma and indirectly through primary effects on physical health and community wellbeing

Prenatal maternal stress leads to adverse pregnancy, newborn, and generational outcomes

The “two-hit” model of psychological and inflammatory stress demonstrated that maternal psychological stress induced anxiety in male and female offspring adults, whereas the inflammatory stress increased exploratory and risk-taking behavior only in adult female offspring.

→ | <https://doi.org/10.12688/f1000research.27157.1>

The cycle of health impacts following climate related exposures during pregnancy



A US survey of health professional suggests that nearly 0% of obstetrics and gynaecologist practitioners discuss environmental impacts of health with their patients!

→ | doi.org/10.1007/s40572-022-00345-9

The Developmental Origin of Health and Disease (DOHD) theory:

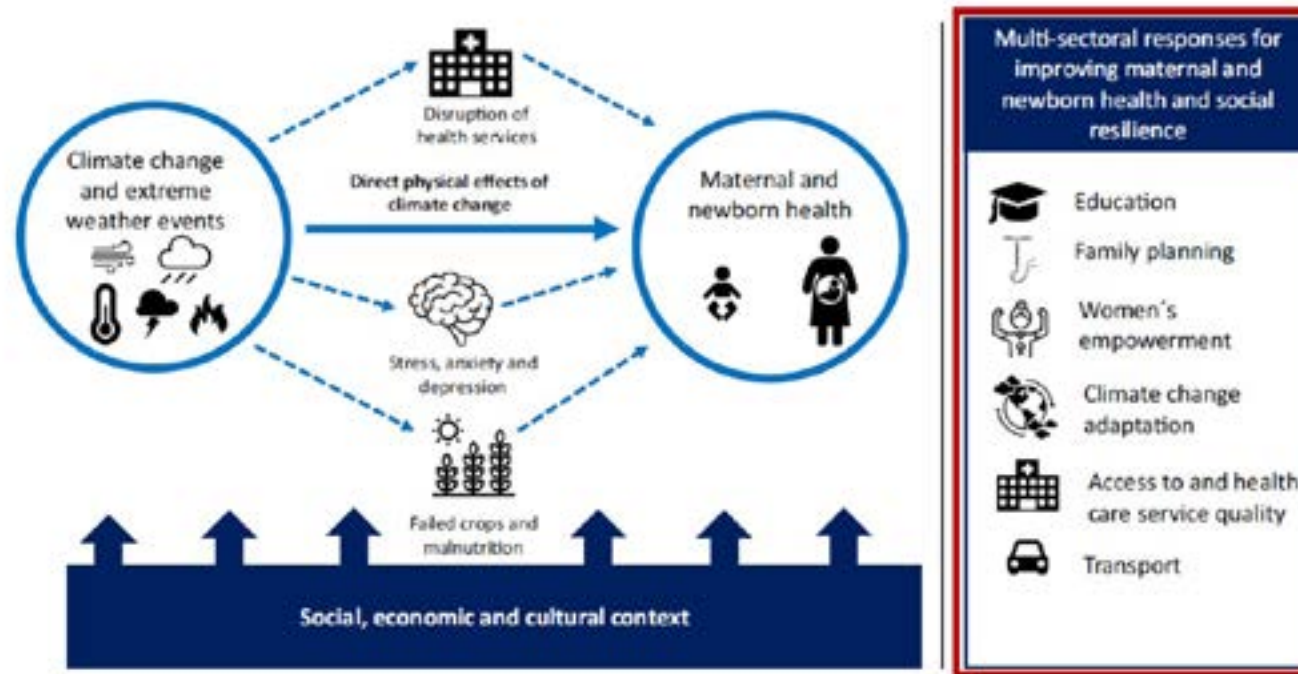
Environmental perturbation(s) during pregnancy (and other developmentally critical periods) have significant immediate and long-term health impact for both mother and offspring

Pregnant women who have pregnancy complications are more likely to experience recurrence in subsequent pregnancy and have greater risk of cardiovascular and metabolic diseases later in life.

Babies affected by preterm birth and low birthweight are more likely to develop subsequent health complications including neurodevelopmental disorders, immunologic complications, obesity, and cardiovascular diseases, all of which put them at higher risk of adverse pregnancy outcomes if they become pregnant.

The impact of climate change on pregnancy health is not limited to this time window, but may propagate health risk across an individual's lifespan and even into future generations.

Framework for the direct and indirect effects of climate change on maternal and neonatal health and the multisectoral responses needed to strengthen resilience



complications so that adequate and timely treatment to prevent mortality and morbidity can be provided, with a focus on quality of care during childbirth.

National adaptation plans describe the strategies and investments needed to adapt to climate change. Both climate and health planning should consider improving access to comprehensive family planning services and investing in education for girls and boys. Investments in sexual and reproductive health services will address the unmet need in family planning, which alone could prevent 54 million unintended pregnancies as well as 26 million fewer and often unsafe abortions, and prevent 79 000 maternal and 600 000 new-born deaths globally each year.

Health-promoting strategies and communication campaigns should also include education on the risks of heat stress and how to mitigate these risks. Delaying first time pregnancy to allow young girls to complete schooling and spacing of pregnancies has lifelong benefits for women, reducing maternal nutritional deficits such as anaemia and allowing families with reduced resources to prosper. In addition, empowering women will have direct down-stream positive effects on the resilience of societies, with highest gains in low-resource settings.

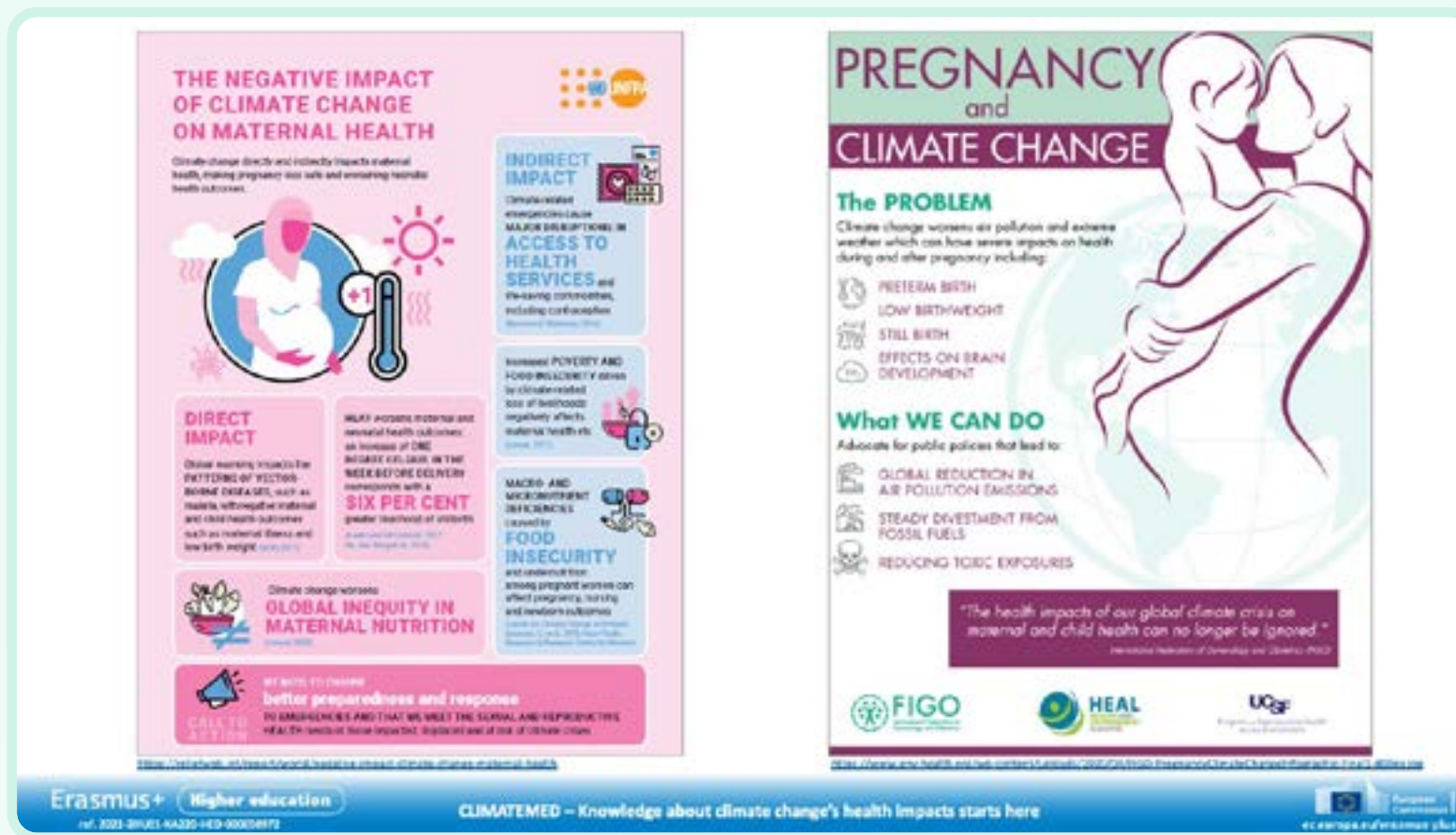
→ <https://obgyn.onlinelibrary.wiley.com/doi/10.1111/aogs.14124>

Women and neonates are among the most vulnerable groups across a range of social and cultural contexts. Identifying pregnant women and neonates as a risk group during climate-related events such as heat extremes is becoming an emerging need for an adequate policy and public health response to mitigate the risk of heat on adverse pregnancy and neonatal outcomes.

Low-resource settings have poor resilience and adaptive capacity to climate change. Research is required to assess and quantify the differential impacts across settings of climate change and heat waves on maternal and perinatal health outcomes.

Research efforts therefore need to identify available, efficient and low-cost interventions to mitigate the health effects of climate change globally, with a particular focus on vulnerable populations, and in geographic regions where there is a paucity of data and where the burden of poor maternal and neonatal health outcomes is the highest.

Pregnancy-related complications that can arise from extreme heat can be detected and treated with timely antenatal and intrapartum care. The World Health Organization has updated guidance on antenatal care and intrapartum care, with an increased number of antenatal care visits to a minimum of eight. This approach has proven to reduce perinatal mortality and the timely detection of pregnancy-related



Impacts of climate change on pregnancy outcomes

Policy, clinical, and research strategies for adaptation and mitigation should be continued, strengthened, and expanded with cross-disciplinary efforts.

Top priorities should include

- (a) reinforcing and expanding policies to further reduce emission,
- (b) increasing awareness and education resources for healthcare providers and the public,
- (c) facilitating access to quality population-based data in low-resource areas, and

→ (d) research efforts to better understand mechanisms of effects, identify susceptible populations and windows of exposure, explore interactive impacts of multiple exposures, and develop novel methods to better quantify pregnancy health impacts.

→ | doi.org/10.1007/s40572-022-00345-9

Impact of climate change on mental diseases, occupational load

Learning outcomes

Upon successful completion of the lesson, students will be able to

- understand the relationship between climate change and mental health problems;
- identify populations who are mostly at risk of mental health and stress-related disorders due to climate change;
- recognize the regional characteristics of climate change related poor mental health;
- understand the possible biological mechanisms linking mental health and heat;
- support individuals and communities in coping with a disaster or traumatic event;
- understand the effect of climate change on the health care system and workforce;
- classify the key threats of climate change to workers' health;
- understand the conceptual framework of the relationship between climate change and occupational safety and health.

How is Climate Change Affecting Health?

Affecting Health Directly

- Extreme Heat
- Air Pollution
- Extreme Weather

Spreading Disease

- Diseases Spread by Insects, Ticks, and Rodents
- Contaminated Water
- Contaminated Food

Destroying & Disrupting Food Supplies

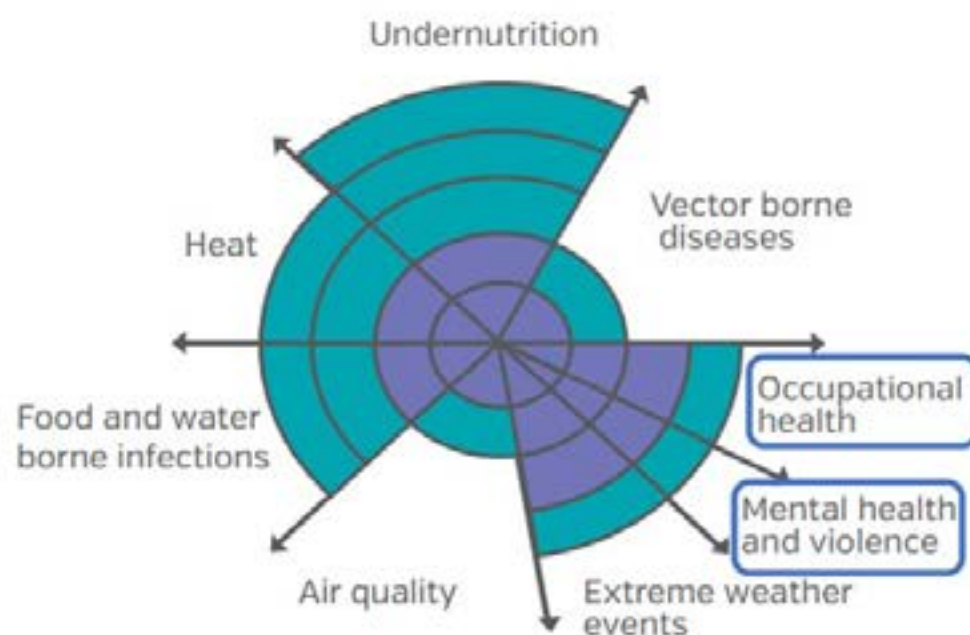
- Hunger and Malnutrition

Disrupting Well-Being

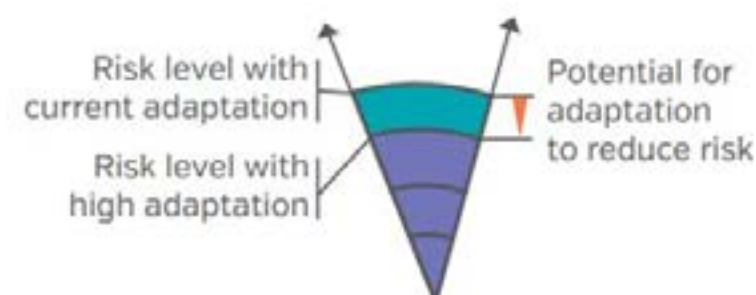
- Mental Health Problems

Future projections by the Intergovernmental Panel on Climate Change (IPCC)

2080-2100 “Era of Climate Options”



Risk and potential for adaption



- Qualitative assessment of the health impacts from climate change, with and without adaptation measures.
- The width of the slices gives an indication of the attributable burden for each health impact, and the light blue area indicates the proportion that could be avoided through strong adaptation measures.

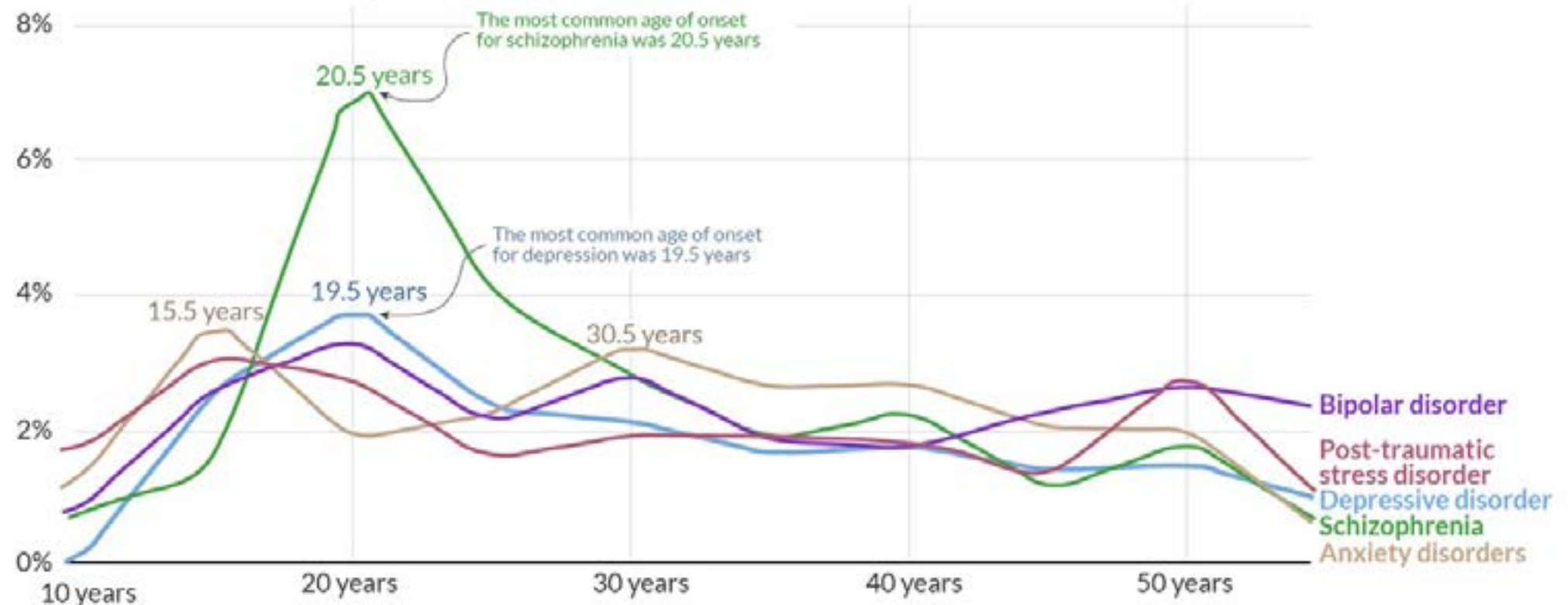
Source: Climate And Health Country Profiles – 2015, A Global Overview, WHO 2015

Mental disorders

Age of onset of mental health disorders

Our World
in Data

Share for whom the disorder begins at a given age



Source: Marco Solmi et al. (2021). Age at onset of mental disorders worldwide: large-scale meta-analysis of 192 epidemiological studies. *Nature Molecular Psychiatry*.
OurWorldinData.org – Research and data to make progress against the world's largest problems. Licensed under CC-BY by the author Saloni Dattani.

Source (accessed 14.06.2023): <https://ourworldindata.org/mental-health>

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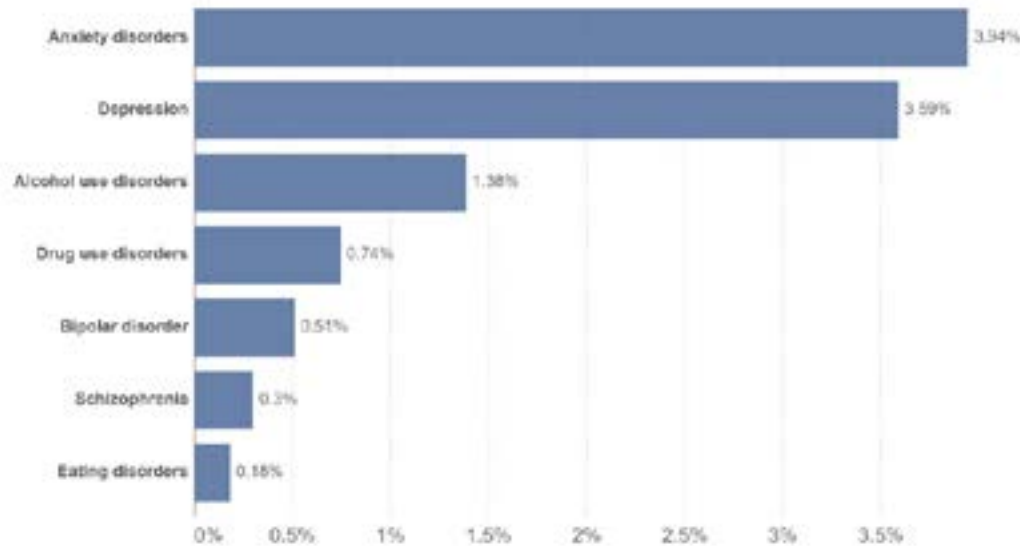
Major depression, schizophrenia, bipolar disorder, obsessive compulsive disorder, panic disorder, post traumatic stress disorder, borderline personality disorder, etc.

„A Mental Disorder is a health condition characterized by significant dysfunction in an individual's cognitions, emotions, or behaviors that reflects a disturbance in the psychological, biological, or developmental processes underlying mental functioning.”
[American Psychiatric Association (2012)]

- can affect persons of any age, race, religion, or income
- not the result of personal weakness, lack of character or poor upbringing

Prevalence by mental and substance use disorder, World, 2019

Share of the total population with a given mental health or substance use disorder. Figures attempt to provide a true estimate (going beyond reported diagnosis) of disorder prevalence based on medical, epidemiological data, surveys and meta-regression modelling.



Source: IHME, Global Burden of Disease (2019)

OurWorldInData.org/mentalhealth - CC BY

- Anxiety and post-traumatic stress disorder
- Other health consequences of intensely stressful exposures are also a concern (pre-term birth, low birth weight, maternal complications)

→ Possible distress associated with environmental degradation and displacement and the anxiety and despair that knowledge of climate change might elicit in some people → ECO-ANXIETY

→ https://www.cdc.gov/climateandhealth/effects/mental_health_disorders.htm

It's estimated that 970 million people worldwide had a mental or substance use disorder in 2017. The largest number of people had an anxiety disorder and depression, estimated at around 3.6-4 percent of the population.

Mental Health and Stress-related Disorders

→ Some patients with mental illness are especially susceptible to heat

- Suicide rates are rising with high temperatures, suggesting potential impacts from climate change on depression and other mental illnesses.

- Dementia is a risk factor for hospitalization and death during heat waves.
- Patients with severe mental illness, such as schizophrenia, are at risk during hot weather → their medications may interfere with temperature regulation or even directly cause hyperthermia.

→ Following disasters, mental health problems increase

- Both among people with no history of mental illness, and those at risk - a phenomenon known as "common reactions to abnormal events"

Eco-Anxiety

Eco-anxiety is the distress caused by climate change where people are becoming anxious about their future.

There are other terms used to understand environmentally-induced distress.

- Ecological grief
- Solastalgia
- Eco-angst
- Environmental distress



Negative physical behaviors associated with climate change:

- Being physically sick
- Experiencing panic attacks
- Adverse emotional reactions such as irritability, weakness, sleeplessness, sadness, depression, numbness, helplessness, hopelessness, guilt, frustration or anger
- Feeling scared or uncertain
- Being in a state of paralysis that manifests as apathy

Positive emotions or behaviors:

- Feelings of hope, empowerment, and connection, particularly when associated with collective action
- These feelings can also be a source of motivation for active engagement and focus on mitigation efforts

Many people report fearing for themselves, their children and future generations with deep feelings of loss, hopelessness, and anger as they witness the effects of climate change.

Ecological grief explains grief felt in response to experienced or anticipated losses in the natural world

Solastalgia is defined as the distress that is produced by environmental change impacting on people while they are directly connected to their home environment

Eco-angst is a feeling of despair at the fragile condition of the planet

Environmental distress is due to people's lived experience of the desolation of their home and environment.

Emotions associated with eco-anxiety link to general anxiety - a negative emotionality characterized by physical symptoms and future-oriented apprehension where eco-anxiety focuses on concerns for climate change.

While negative emotions are often associated with eco-anxiety, they can also be a healthy psychological adaptation and response to threat.

Eco-Anxiety

Eco-anxiety is the distress caused by climate change where people are becoming anxious about their future.

There are other terms used to understand environmentally-induced distress.

- Ecological grief
- Solastalgia
- Eco-anxst
- Environmental distress



<https://doi.org/10.1016/j.jmb.2019.05.004>

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Eco-Anxiety – Demographic characteristics

Most studies focused on youth experiences and their emerging concerns for climate change

Children are more vulnerable to climate change's mental health effects as they have stronger responses to extreme weather events like PTSD, depression, and sleep disorders.

Younger participants (18–35 years) reported higher scores than older adults when reporting on the degree of climate anxiety impacting their ability to function.

Females and those in younger age groups were more distressed overall about climate change than males and those over the age of 35 years.

Women have more significant stress and anxiety as they are more behaviorally engaged with higher rates of post-traumatic stress disorder (PTSD) following a disaster compared to men.

→ <https://doi.org/10.1016/j.joclim.2021.100047>

Tips for Overcoming Eco-Anxiety



Knowing the enemy is fundamental and that is where climate change education comes in. Raise your own and others' awareness of the problem.



Commit to responsible consumption and recycling to protect the environment as much as possible. Also reduce your plastics consumption.



Do sustainable activities, such as setting up an urban garden or plogging (going running and picking up plastic from the ground).

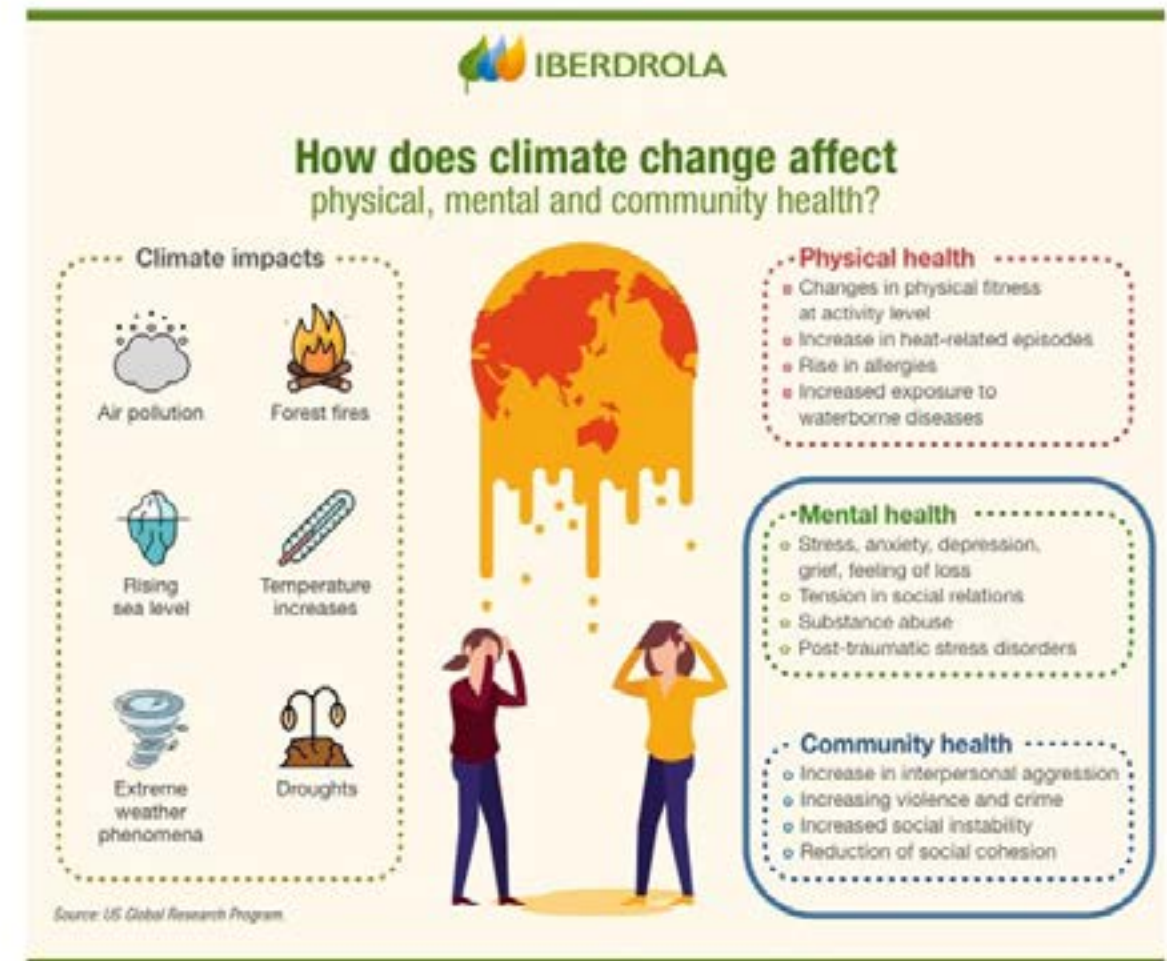


Commit to sustainable mobility and sustainable food. Your health and that of the planet will be grateful.



Avoid those little things that pollute, such as leaving the tap running or throwing chewing gum on the ground, because even the smallest detail counts.

Source (accessed 14.06.2023): <https://www.iberdrola.com/social-commitment/what-is-ecoanxiety>



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Is there an association between hot weather and poor mental health outcomes?

Regarding high temperatures, for each 1°C increase in temperature the mental health-related

- mortality increased with a RR of 1.022
- morbidity increased with a RR of 1.009

The greatest mortality risk was attributed to substance-related mental disorders, followed by organic mental disorders.

A 1°C temperature rise was also associated with a significant increase in morbidity such as mood disorders, organic mental disorders, schizophrenia, neurotic and anxiety disorders.



Is there an association between hot weather and poor mental health outcomes? A systematic review and meta-analysis

Regarding high temperatures, for each 1 °C increase in temperature the mental health-related

- mortality increased with a RR of 1.022 (95%CI: 1.015–1.029)
- morbidity increased with 1.009 (95%CI: 1.007–1.015)

The greatest mortality risk was attributed to substance-related mental disorders (RR, 1.046; 95%CI: 0.991–1.101), followed by organic mental disorders (RR, 1.033; 95%CI: 1.020–1.046).

A 1 °C temperature rise was also associated with a significant increase in morbidity such as mood disorders, organic mental disorders, schizophrenia, neurotic and anxiety disorders.

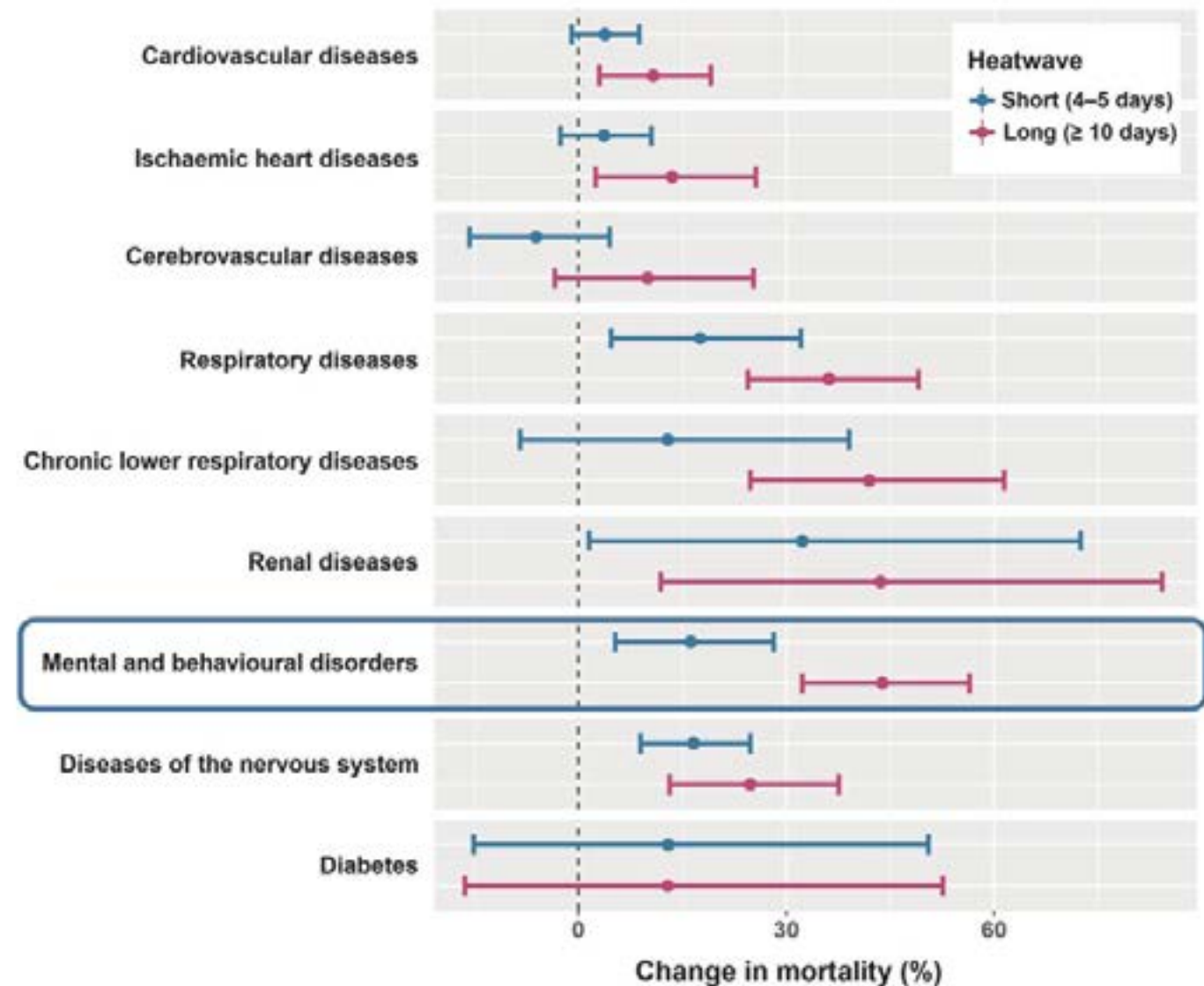
Findings suggest evidence of vulnerability for populations living in tropical and subtropical climate zones, and for people aged more than 65 years.

- <https://doi.org/10.1016/j.envint.2021.106533>

Mortality risk related to heatwaves in Finland

Percentage change (95% confidence interval) in daily cause-specific mortality during short and long heatwaves.

In those aged 65–74 years, statistically significant increase in mortality was detected for cerebrovascular diseases, chronic lower respiratory diseases, and **mental and behavioural disorders**.



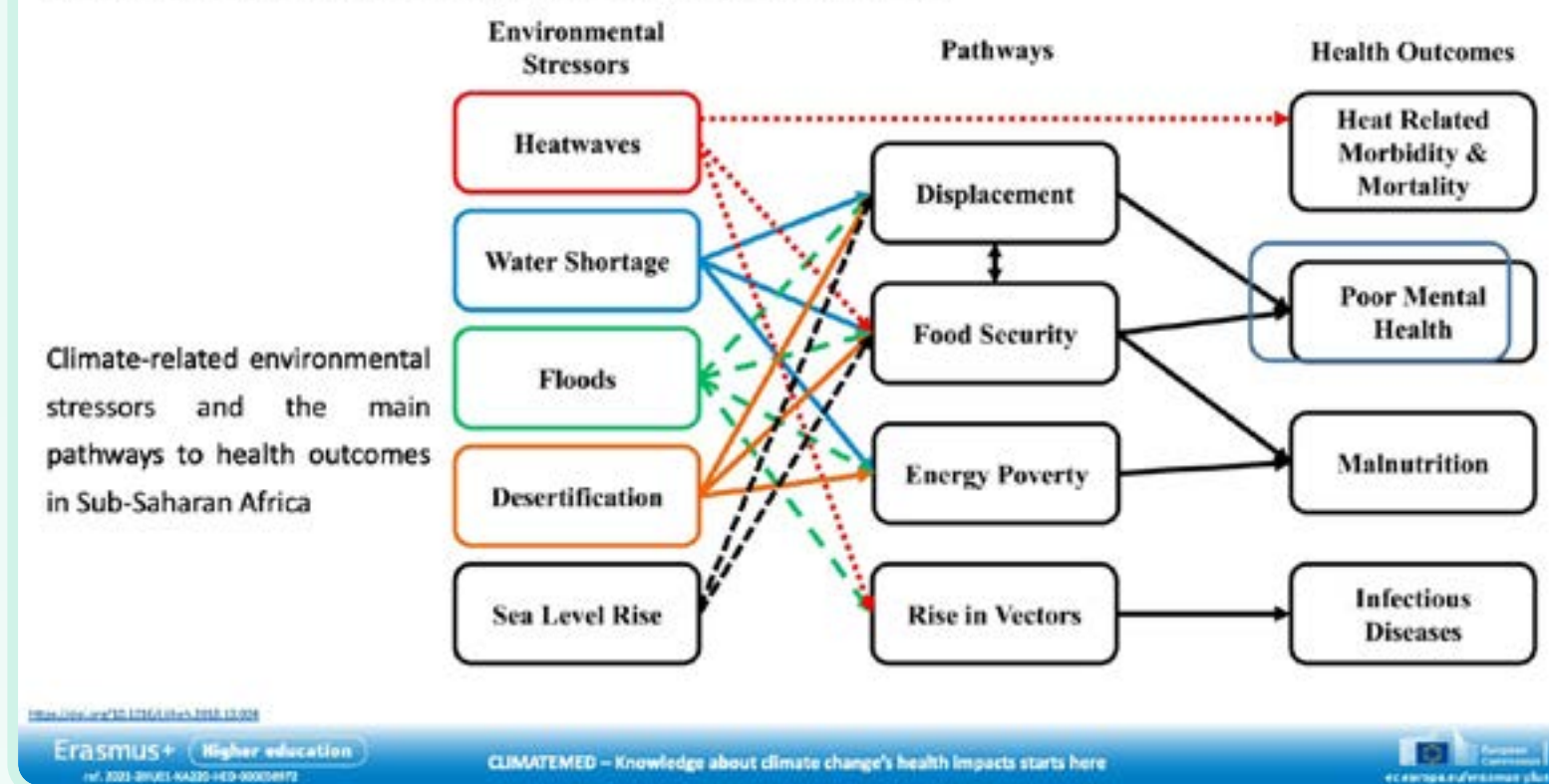
<https://doi.org/10.1016/j.ersys.2023.1111501>

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Climate-related migration in Sub-Saharan Africa



infectious diseases trends, and providing mental healthcare for migrants.

→ <https://doi.org/10.1016/j.ijheh.2018.10.004>

Heatwaves, water stress, desertification, flooding, and sea level rise are environmental stressors that increase morbidity, mortality, and poor mental health in Sub-Saharan Africa.

The intensity and frequency of extreme climatic events can cause mental health disorders including posttraumatic stress disorder, depressive disorders, anxiety, and other serious conditions.

In addition, due to their forced displacement, many climate migrants can experience negative consequences on their sense of identity and belonging, factors that can intensify psychosocial distress.

While most migration is intra-African, climate change is also affecting migration patterns outside the continent.

Health systems should be adapted to meet the increased demand for mental health services relating to climate change.

Healthcare facilities in Arusha (Tanzania), for example, provide free psychiatric and psychological counseling to under-privileged populations.

Train health professionals and students in schools of medicine and public health in adaptation of health systems in the global south and north to current and projected climate-exacerbated morbidity, changes in

Bushfires in Australia

Health effects of the fires, yet to be quantified, include acute and lingering **mental health impacts** of experiencing

- trauma of evacuation and dislocation;
- loss of family and friends, property, livelihoods and natural amenity;
- and fear about the future.

Potential impacts on **frontline responders!**



<https://www.sbs.com.au/news/2019/10/26/2019-20-bushfires-022-02782-w>

Potential impacts on frontline responders (especially on firefighters):

- physical and mental exhaustion,
- emotional trauma,
- chronic exposure to smoke,
- loss of income for many volunteer firefighters.

→ | <https://doi.org/10.5694/mja2.50869>

Australia's epic wildfires expanded ozone hole and cranked up global heat. Temperatures in the stratosphere increased by 3 °C in some places.

→ | <https://www.nature.com/articles/d41586-022-02782-w>

The 2019-20 bushfires lasted three months in total, spanned 10 million hectares, destroyed more than 3000 homes, and resulted in 33 deaths directly.

The thick smoke for weeks resulted in record levels of air pollution, and in an estimated 417 excess deaths, 1305 asthma emergency department presentations, and 3151 hospital admissions for cardiovascular and respiratory conditions.

→ | <https://doi.org/10.5694/mja2.50869>

Other health effects of the fires, yet to be quantified, include acute and lingering mental health impacts of experiencing

- trauma of evacuation and dislocation;
- loss of family and friends, property, livelihoods and natural amenity;
- and fear about the future.

Possible Biological Mechanisms Linking Mental Health and Heat A Contemplative Review

History

- 1970s: the New York State psychiatric hospital experienced a large number of deaths among patients during heatwaves

Patient characteristics

- Compared to the general population, mental health patients often experience poorer overall health and show increased morbidity and mortality in general

Psychotropic medications

- Many antipsychotic, anticholinergic, antidepressant, sedative, mood stabilizing, and nervous system medicines increase heat vulnerability through inhibition of the adaptive thermoregulative activities of the body.

Heat and brain

- Heat-exposure impairs cognitive function, disturbs execution of effective behavioral responses, and decreases the capacity of both working and short-term memory

Heatwave induced sleep disruptions

- Heatwave-induced sleep-deprivation, the periods involving heat-induced interrupted sleep are likely to contribute to the maintenance and exacerbation of already present mental health symptoms

Environmental awareness and the ability to initiate adaptive behaviors, such as increased fluid intake, appropriate planning of daily activities, or wearing appropriate clothing, may be compromised in some groups of mental health patients, such as those with Alzheimer's disease, dementia, psychosis, schizophrenia, and developmental disabilities.

“Unable to care for oneself” has been identified as an important risk factor in heat-related mortality and may contribute to the ill-health in these patients.

The use of psychotropic medications: by interfering with physiological homeostasis, these medications increase the vulnerability in mental health patients, even when their cognition and ability to care for themselves is unaffected by the disorder.

History

1970s: the New York State psychiatric hospital experienced a large number of deaths among patients during heatwaves

Analysis of mortality data in the New York State psychiatric hospital from 1950 to 1984, stated that during this period the psychiatric patients had double the risk of dying during a heat wave as the general population

California heatwave in 1995: Increased ORs (OR 3.5, 95% CI 1.7–7.3) for death and 20% increase in hospital admission were shown in persons with pre-existing mental health conditions

Mental disorders were also a significant contributor to the 2003 heatwave mortality in Paris (748+ deaths)

In a meta-analysis performed by Bouchama et al. (2007), the authors found that, among preexisting conditions psychiatric illness tripled the mortality risk and was the factor that was most strongly associated with death during heatwaves (OR 3.61, 95% CI 1.3–9.8).

Patient characteristics

Compared to the general population, mental health patients often experience poorer overall health and show increased morbidity and mortality in general.

Psychotropic medications

Many antipsychotic, anticholinergic, antidepressant, sedative, mood stabilizing, and nervous system medicines increase heat vulnerability through inhibition of the adaptive thermoregulative activities of the body.

Anticholinergic drugs or drugs with anticholinergic effects impair sweating, reduce heat elimination, thereby increasing the vulnerability of their users in heatwaves.

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Increased BBB permeability in hyperthermia may increase the vulnerability of the brain to both pathogen organisms and toxic neurochemicals.

The pathology of severe hyperthermia includes edemas and swollen nerve cells with disintegrated nuclei in various brain areas and exerts often irreversible neurological damage.

Heat stress has been shown to increase the secretion of hypothalamo-pituitary-adrenocortical (HPA) hormones adrenaline, noradrenaline, and cortisol, but also increase the circulatory levels of serotonin and hypothalamic levels of both dopamine and serotonin, changes of which are not only likely to affect physiological responses, but affect mood state and cognition.

Sympathomimetic drugs, especially those that act as agonists at the adrenergic receptor, cause hyperthermia through increased cutaneous vasoconstriction (i.e., decreased skin blood flow), while some sympathomimetics also increase metabolic heat production by agitation-related expanded muscular activity.

Neuroleptics (antipsychotics), such as phenothiazines, have both anticholinergic and central thermoregulatory effects and their use is associated with increased risk of heat stroke.

Antidepressants, such as the dual dopamine/noradrenaline reuptake inhibitor bupropion, have been shown to significantly increase core temperature in exercising humans (and both core and brain temperature in exercising rats).

Antipsychotic drugs: Thirst perception may be disturbed by drugs at several levels of the regulation system, which contributes to the development of dehydration.

Heat and brain

Heat-exposure impairs cognitive function, disturbs execution of effective behavioral responses, and decreases the capacity of both working and short-term memory

Increasing body temperatures might influence oxygen delivery to different brain regions and thereby influence the information processing procedure of the CNS.

Heatwave induced sleep disruptions

Human sleep is sensitive to environmental characteristics and even minor environmental changes may lead to sleep disturbances and sleep deprivation.

Potential health effects of sleep-deprivation are likely to increase during heatwaves.

Sleep deprivation strongly correlates with increased mortality and morbidity in epidemiological reports.

Possible Biological Mechanisms Linking Mental Health and Heat A Contemplative Review

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10.3390/ijerph15071515

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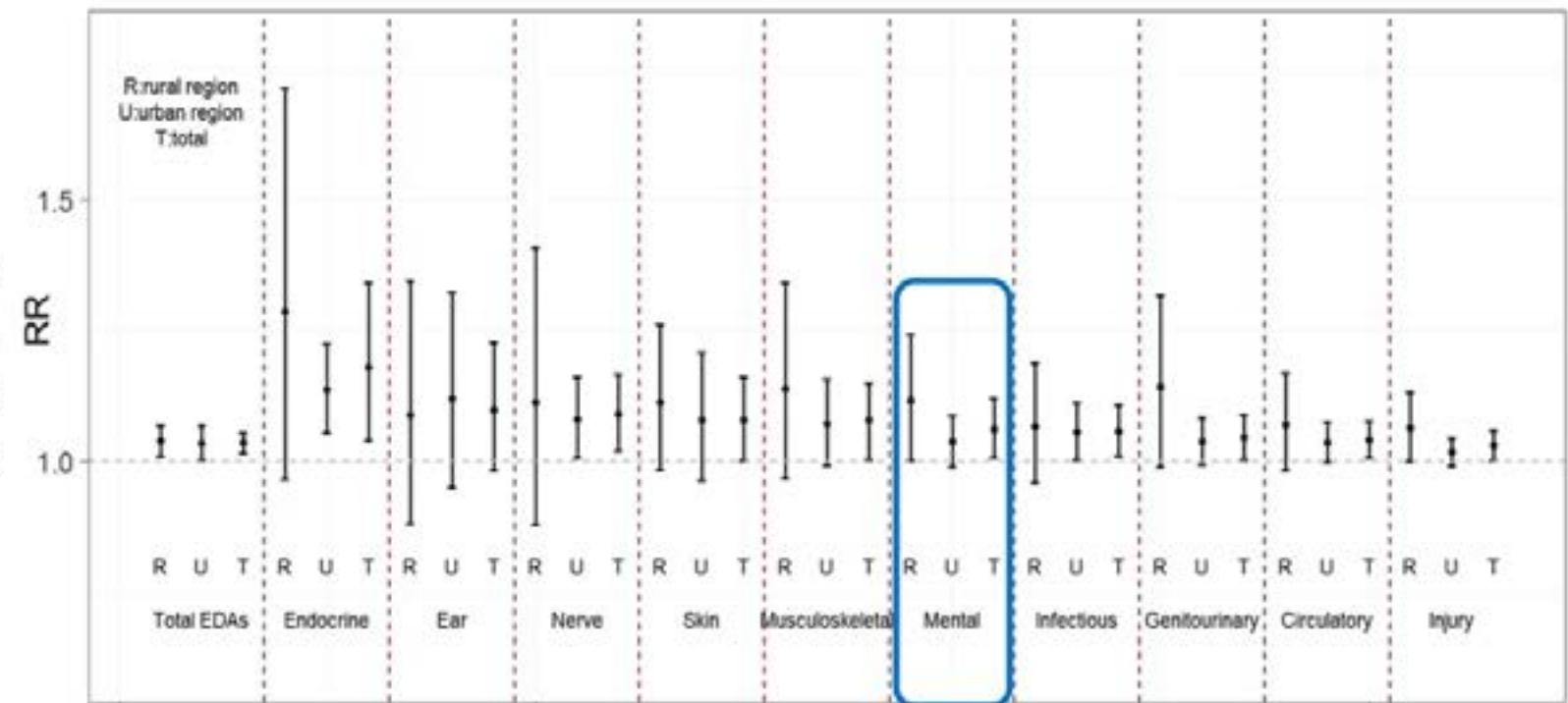
Sleep and emotion interact, and that nearly all psychiatric and neurological disorders (i.e., schizophrenia, affective disorders, addictions, dementia) are associated with sleeping problems.

Heatwave-induced sleep-deprivation, the periods involving heat-induced interrupted sleep are likely to contribute to the maintenance and exacerbation of already present mental health symptoms.

→ | <https://doi.org/10.3390/ijerph15071515>

Heatwave impacts on cause-specific emergency department visits (EDVs)

There were significant pooled effects of heatwaves on total and cause-specific EDVs between urban and rural regions in the eight communities of Queensland, Australia



<https://doi.org/10.1016/j.envres.2018.10.013>

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Pooled effects of heatwaves on cause-specific EDVs between urban and rural regions

The mechanisms underlying the effects of heatwaves on mental and behavioural disorders and diseases of the nervous system mainly include two aspects. First, people with these diseases (e.g., Parkinson's disease)

have less cognitive awareness of the hostile environment and less capacity to adapt the extreme heat owing to their compromised language capacity. Second, the medication that they take to control the diseases affect their thermoregulatory ability.

→ <https://doi.org/10.1016/j.envres.2018.10.013>

Mental Health and Stress-related Disorders

Most at risk:

- Children
- Older adults
- Pregnant and postpartum women
- People with mental illnesses
- People living in poverty
- People who are homeless
- First responders
- People experiencing increased stress
- People who rely on the environment for their livelihood



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Coping with a Disaster or Traumatic Event

During and after a disaster, it is natural to experience different and strong emotions.

Coping with these feelings and getting help when you need it will help you, your family, and your community recover from a disaster.

People with preexisting mental health conditions should continue with their treatment plans during an emergency and monitor for any new symptoms.

For more informations, see:

- <https://emergency.cdc.gov/coping/index.asp>
- <https://www.samhsa.gov/disaster-preparedness>
- https://www.cdc.gov/climateandhealth/effects/mental_health_disorders.htm

Mental health problems - what individuals can do

Know your signs of stress

- Difficulty concentrating and making decisions
- Reduced interest in usual activities
- Disbelief, shock, and numbness
- Anger, tension, and irritability
- Fear and anxiety about the future

For more informations, see:

<https://emergency.cdc.gov/coping/index.asp>

<https://www.samhsa.gov/disaster-preparedness>

Socialize with friends and family

- Connect and talk with your friends, family members, and your community

Take mental breaks

- Engage in activities to decompress such as exercise, listening to music, or spending time with a friend

Ask for help

- Seek professional help when symptoms are disrupting your day-to-day activities

Source (accessed 14.06.2023): https://www.cdc.gov/climateandhealth/site_resources.htm
https://www.cdc.gov/climateandhealth/effects/mental_health_disorders.htm

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Mental health problems - what communities can do

Prepare an emergency plan

- Develop behavioral health plans for disasters
- Include clear messaging about access to mental health services and crisis counseling

Source (accessed 14.06.2023):

https://www.cdc.gov/climateandhealth/site_resources.htm

CLIMATE AND HEALTH: PLANNING WORKSHEET
PREPARING A COORDINATED COMMUNITY RESPONSE

This leave-behind worksheet is designed to help community groups coordinate efforts to adapt to the local health impacts of our changing climate. It is intended to help facilitate shared community response planning with key stakeholders. The Health Impacts Cards (described in section 3) are designed to complement this planning worksheet. It is recommended that the worksheet only be used after the audience has been exposed to the topic of climate and health through other means such as an introductory presentation, videos, or discussion.

First, list the sectors/organizations participating in today's planning session:

I. ASSESSING COMMUNITY RISK (Complete as a group)
Start by identifying the climate-related health risks in your community today. Refer to the health impact cards for details and circle all that apply.

a. Extreme Heat	b. Contaminated Food
c. Extreme Weather	d. Contaminated Water
e. Air Pollution	f. Hunger and Malnutrition
g. Diseases Spread by Insects, Ticks, and Rodents	h. Mental Health Problems

Based on the issues you circled above, which groups of people in your community are most at-risk?

a. Older adults	b. Outdoor workers or agricultural workers
c. Young children	d. People with physical disabilities
e. People who lack air conditioning	f. People taking certain medications
g. First responders	h. People living in poverty
i. People with weakened immune systems	j. Student athletes
k. Homeless individuals	l. Pregnant women
m. People with chronic illnesses, allergies, or pre-existing respiratory, cardiac, or mental health conditions	
n. People using private well water	o. Other _____

II. MAPPING RESOURCES (Complete as a group)
Next, identify where you have community resources to address the above health impacts and reach at-risk groups.

Of the at-risk groups identified above, which does your sector/organization have the most access to?
In your experience, what are the best ways to reach them?

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MENTAL HEALTH PROBLEMS **CASE STUDY**

Oregon Health Authority, Climate and Health Program

Problem: More exposure to extreme events in Oregon, such as storms and wildfires, can lead to economic stress and displacement, which can increase the risk of mental health conditions like anxiety, depression, and post-traumatic stress, even among people with no history of mental illness.

Approach: To communicate various climate impacts within a local context, the Climate and Health Program released a collection of digital stories from partners and community members. Featured mental health professionals highlighted the connection between climate change and mental health and the need for community collaboration to prepare for and respond to its effects.

Results: The Oregon Health Authority continues to embed mental health into its planning processes and maintains partnerships with mental health agencies across the state through its Public Health Emergency Preparedness program. These collaborations include health provider training to support trauma care that recognizes and responds to the effects of climate change.



Centers for
Disease Prevention
National Center for
Environmental Health

CLIMATE-READY STATES
AND CITIES INITIATIVE

[cdc.gov/climateandhealth](https://www.cdc.gov/climateandhealth)

Communities are developing a coordinated response to health risks by using CDC's Building Resilience Against Climate Effects (BRACE) framework, a five-step process for climate adaptation.

Source (accessed 14.06.2023): <https://www.cdc.gov/climateandhealth/pubs/CDC-HealthHarmCards-508.pdf>

Recommendation:

It would be useful for local health authorities and service providers to incorporate mental health impacts into their heatwave warning systems, and to have public health policies and guidelines addressing preventable heat-related mental health mortality and morbidity.

<https://doi.org/10.1016/j.envint.2021.106533>

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How does climate change affect the health care system?



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Climate change affects every aspect of the health care system.

It can lead to major financial losses for health care delivery systems.

Climate change also exacerbates existing inequities in health and health care.

Global warming hampers access to health services as well as the quality of services provided.

Costs: worsening of the health of millions pushes up health care costs.

Caring for the people facing immediate impacts, as well as people with new or

exacerbated chronic conditions, like cardiovascular or respiratory illness.

One study of 10 climate events from 2012 in the U.S. revealed that the health-related costs, including hospital admissions, emergency department visits, other medical costs and lost wages totalled \$10 billion in 2018 dollars.

Equity: Climate change does not affect people equally; in fact, it deepens preexisting inequities by taking the greatest toll on those already at heightened risk.

The people in greatest danger are:

- low-income people
- people of color, especially Indigenous communities
- workers in certain hazardous occupations, such as first responders and construction workers
- people living in environmentally fragile areas
- people with preexisting health conditions
- older adults
- children
- people with disabilities
- people who are experiencing homelessness.

Research shows that extreme weather events like hurricanes are associated with long-term racial disparities and can even reverse previous equity gains.

For example, Black survivors of Hurricane Katrina have more frequently reported hurricane-related problems with personal health, emotional well-being, and household finances.



How does climate change affect the health care system?



Access: Extreme climate events may lead to health system disruption.

Hospitals may need to be evacuated, facilities may be damaged or closed, power outages may disrupt care, and damaged roads or transit systems may prevent people from getting to health facilities.

When Hurricane Sandy struck New York City in 2012, Bellevue Hospital, which serves more than 500,000 patients annually, was forced to close temporarily and move patients elsewhere.

Quality: When some hospitals are forced to close, others can become stretched beyond their capacity.

Overcrowding and the boarding of patients in emergency departments are associated with decreased quality of care.

In addition, disruptions to the supply chain may reduce the availability of critical medicines or medical devices.

When Hurricane Maria damaged a key saline manufacturing plant in Puerto Rico, it led to dire shortages of a critical medical supply in both the territory and the rest of the U.S.

→ <https://www.commonwealthfund.org/publications/explainer/2022/may/impact-climate-change-our-health-and-health-systems>

How does climate change impact the health care workforce?



Mental health problems and burnout among healthcare workers
(Source: healthcare.com, accessed 14.06.2022)



Assam Health Workers "Borrow" Boats To Reach To Flood-Victims Amid COVID
(Source: nbc.com/india-news, accessed 14.06.2022)



As drought tightens its grip on Kenya, a motorcycle ambulance is helping women to access critical health care
(Source: un.org/kenya, accessed 14.06.2022)



The Increasing Importance of Disaster Medicine
(Source: emergency.com, accessed 14.06.2022)



Houses burn as huge wildfire forces evacuation of six Jerusalem-area communities
(Source: timesofisrael.com, accessed 14.06.2022)

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Health care professionals experience the physical and mental health risks of climate change more acutely than the general population.

Climate change not only disrupts their lives but also makes their jobs more challenging, raising the risk of burnout.

Storms, floods, wildfires, and other extreme events often prevent them from traveling to health care facilities. As more people get sick because of climate change, there will be a greater need for a larger, climate-ready workforce.

Because climate risks to health care may be new to some parts of the world, it's vital for

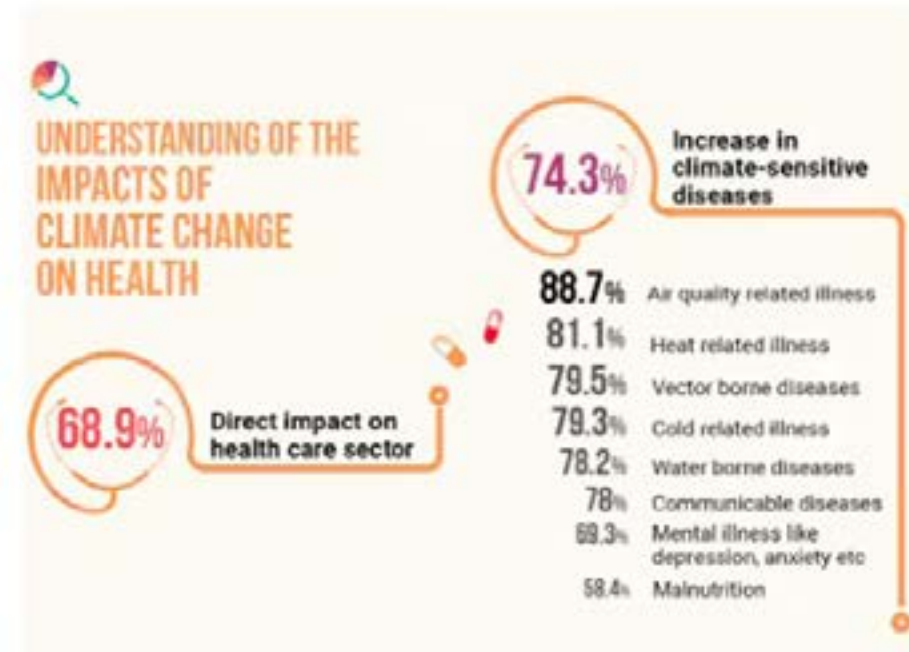
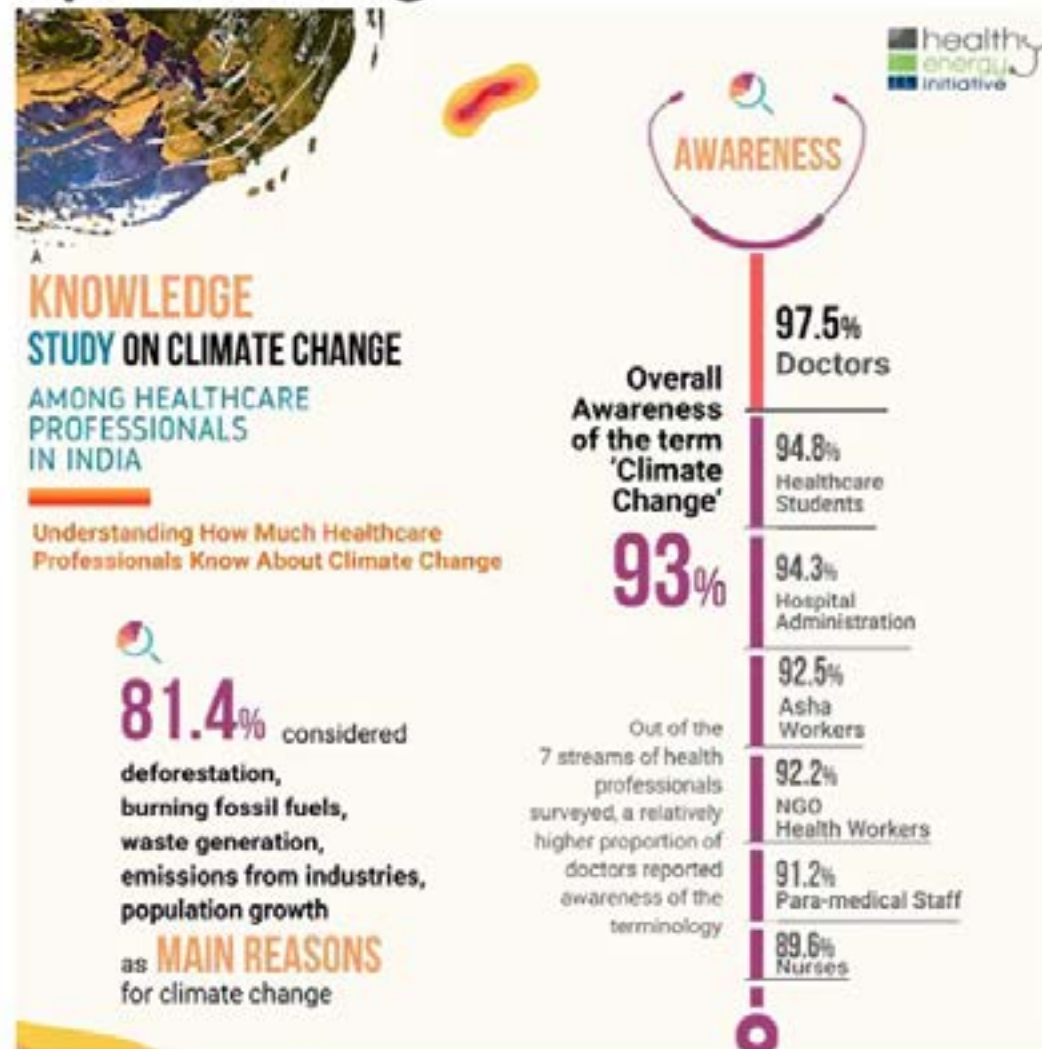
the health care workforce to be trained in identifying and addressing these risks.

In the event of health system disruption, the workforce needs to quickly adapt to delivering care under highly challenging circumstances.

One study from Australia found that in a region inhabited by underserved populations, the effects of climate change were causing a third of health care workers to consider moving elsewhere.

→ <https://www.commonwealthfund.org/publications/explainer/2022/may/impact-climate-change-our-health-and-health-systems>

Knowledge, attitudes and practices related to climate change and its health aspects among the healthcare workforce in India



Source (accessed 14.06.2023): <https://en.gaonconnection.com/the-healthcare-sector-has-a-responsibility-to-address-climate-change-and-reduce-its-carbon-footprint-study/>

Sambath et al.: Knowledge, attitudes and practices related to climate change and its health aspects among the healthcare workforce in India – A cross-sectional study. The Journal of Climate Change and Health. 2022. <https://doi.org/10.1016/j.joclim.2022.100147>

Climate Change and the Health of Workers



Key Threats to Workers' Health

- Heat Illnesses
- Respiratory Illnesses
- Physical and Mental Health Effects
- Insect- and Tick-Related Diseases
- Pesticide-Related Effects

<https://www.eea.europa.eu/en/climate-matters/climate-change-and-health-workers>

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Climate Change and the Health of Workers

Heat Illnesses can occur when a person is exposed to high temperatures and their body cannot cool down.

Respiratory Illnesses are associated with air quality, pollens, wildfires, indoor environments

Physical and Mental Health Effects floods, storms, droughts, and wildfires often require complex emergency response, recovery, and rescue operations and these operations put many types of workers at risk

Insect- and Tick-Related Diseases warmer temperatures associated with climate change can increase mosquito development and biting rates

Pesticide-related Effects changes in pest populations and distribution are expected to increase the use of pesticides in agriculture

Overlapping vulnerabilities certain workers may be part of other groups vulnerable to climate change thus their health risk are increased

Heat-related fatigue can also impact a worker's alertness to job-related dangers, which can increase the chance of injury or death.

Construction, utility, transportation, and other outdoor workers face additional risks from urban heat islands, which can intensify both daytime and nighttime temperatures.

2. Respiratory Illnesses

Air quality

Climate change will impact air quality - some outdoor air pollutants (O₃ and PM) are expected to increase.

Outdoor workers, including agricultural and migrant workers, may be more exposed to these pollutants, which can lead to respiratory illnesses, including asthma.

Climate change can also increase the frequency and severity of some extreme weather events, including heavy rainfalls. More humidity and moisture can lead to increases in mold, bacteria, and pests, which can worsen asthma and other respiratory effects for indoor workers in damp environments.

Many workers are more vulnerable to the health impacts of climate change than the general population because:

They work outdoors, in fields such as agriculture, construction, or transportation. This can make them more exposed to extremes in temperature and weather, poor air quality, and disease-carrying pests.

They work in hot indoor environments that lack adequate air conditioning, such as in manufacturing plants, warehouses, and other facilities.

They are emergency response workers, such as paramedics, firefighters, and police officers. These workers are more likely to be exposed to

climate-related risks such as wildfire smoke or flooding from a heavy rainfall.

1. Heat Illnesses

Heat illnesses can occur when a person is exposed to high temperatures and their body cannot cool down.

As the climate changes, average and extreme temperatures are increasing, along with heat waves.

These changes can put indoor and outdoor workers at greater risk of heat-related illnesses, such as heat stroke and exhaustion, especially in jobs that are physically demanding.

Climate Change and the Health of Workers

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3. Physical and Mental Health Effects

As the climate changes, some extreme weather events are becoming more frequent or intense.

Floods, storms, droughts, and wildfires often require complex emergency response, recovery, and rescue operations.

These operations put many types of workers at risk, including first responders, health care workers, and those involved in pre- and post-disaster support.

Workers can experience both physical and mental health effects from these events.

Physical impacts can include deaths, injuries, and illnesses.

Mental health effects can include anxiety, depression, and post-traumatic stress disorder.

Pollens

Earlier spring warming, precipitation changes, and rising temperatures and carbon dioxide concentrations can increase the length and severity of the pollen season.

Outdoor workers, such as farmers, ranchers, and other agricultural workers, may face more exposure to pollen and other allergens that cause hay fever or asthma.

→ <https://www.epa.gov/climateimpacts/climate-change-and-health-workers>

Wildfires

As the climate changes, the increasing frequency and intensity of wildfires will lead to increased respiratory health risks for firefighters (lung inflammation and decreased lung function).

Indoor environments

Changes in the climate can worsen allergens and certain outdoor pollutants, which can then make their way indoors.

4. Insect- and Tick-Related Diseases

Warmer temperatures associated with climate change can increase mosquito development and biting rates.

Increased rainfall can create more breeding sites for mosquitoes.

Outdoor workers, such as agricultural workers, could be at higher risk of exposure to tick and insect bites that cause Lyme disease, West Nile virus, and other diseases.

Climate Change and the Health of Workers

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Some outdoor workers may also live in communities with poor air quality.

Older adult workers with existing health conditions can be more sensitive to extreme heat.

Workers who are part of immigrant populations can also be more vulnerable to climate hazards since they often have fewer means to prepare and cope.

Most people who contract West Nile virus do not develop any symptoms, but in rare cases, people can experience serious illness and even die.

Lyme disease can cause chronic pain and neurological problems if not treated early.

5. Pesticide-Related Effects

Changes in pest populations and distribution are expected to increase the use of pesticides in agriculture.

Climate change has already contributed to an expanded range for ticks.

These changes could increase pesticide exposures for agricultural workers.

It could also put family members in danger if workers bring pesticide residues into their homes, such as on their skin, tools, and clothing.

Sprayed pesticides can also drift into communities and homes close to farms, increasing residents' risk.

6. Overlapping Vulnerabilities

Certain workers may be part of other groups vulnerable to climate change.

This can increase their health risks.

Climate Change and the Health of Workers – What you can do

Both employees and employers can take steps to reduce the health impacts of climate change, including:

- **Keep cool and stay hydrated.**
Outdoor employees should drink enough water, take breaks, and seek out shade when possible. Employers should require workers to take breaks in a cool location, and make sure that employees don't skip these breaks.
- **Plan, train, and monitor.**
Employers should have a written plan to prevent heat illnesses and train employees to recognize heat hazards and should monitor heat-related conditions at work sites.
- **Check outdoor air quality.**
Look at the local weather reports. Pay attention to wildfire, smoke, and ash warnings.
- **Improve indoor air quality.**
Employers of indoor workers should ensure adequate ventilation and moisture control.
- **Take care of your mental health.**
Employers should ensure mental health services for their employees, especially during and after an extreme weather event or climate-related disaster.
- **Prevent bites.**
Outdoor workers should use insect repellent and wear long-sleeved shirts and pants to prevent mosquito bites and avoid where ticks live. Check yourself for ticks if you have been outdoors, especially during warmer months and if you have been in wooded or grassy areas.
- **Protect workers who handle or come in contact with pesticides.**
Provide training and protective equipment to reduce pesticide exposures, use integrated pest management if it is possible.

Source [accessed 14.06.2023]: <https://www.epa.gov/climateimpacts/climate-change-and-health-workers>

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Climate change and occupational safety and health

- The relationship between global climate change and occupational safety and health has not been extensively characterized.
- A framework was developed for identifying how climate change could affect the workplace, workers and occupational morbidity, mortality, and injury.
- Seven categories of climate-related hazards are identified:
 - 1) *increased ambient temperature*
 - 2) *air pollution*
 - 3) *ultraviolet exposure*
 - 4) *extreme weather*
 - 5) *vector-borne diseases and expanded habitats*
 - 6) *industrial transitions and emerging industries*
 - 7) *changes in the built environment*
- Climate change may result in increasing the prevalence, distribution, and severity of known occupational hazards.

<https://doi.org/10.1080/14493992.2020.1800000>

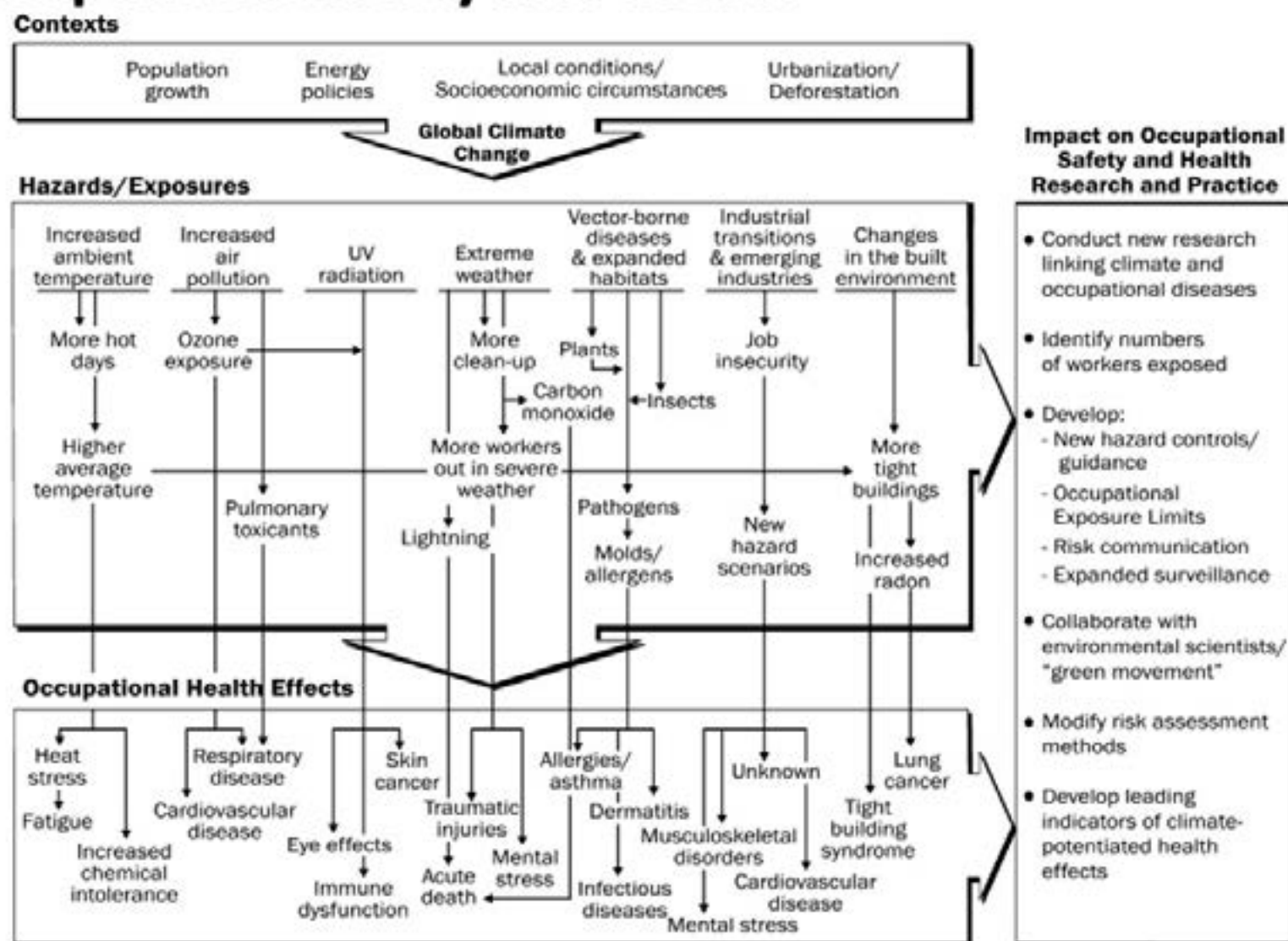
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Climate change and occupational safety and health

Conceptual framework of the relationship between climate change and occupational safety and health



<https://doi.org/10.1080/15459620903066008>

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The impact of climate change on workers' health is affected by other contextual factors, such as:

- population growth
- energy policies
- increasing urbanization and deforestation

These factors along with climate change may lead to an increase in the magnitude and severity of known hazards and result in increasing numbers of workers who would be exposed to them.

→ <https://doi.org/10.1080/15459620903066008>

Climate change and occupational safety and health

Factors that Could Increase Susceptibility to Climate-Related Occupational Hazards

Age	Older workers may have slower elimination of many toxicants. They are also less able to thermoregulate.
Obesity	Inherited and acquired differences in heat tolerance and sweat rate: excess body weight raises metabolic heat production.
Pre-existing disease	Workers with prior heat injury, obesity, or pre-existing illness such as cardiovascular disease or chronic respiratory diseases, elderly, children or others in thermally stressful occupations and who are not acclimatized may be at a greater risk of heat illnesses.
Very small body size, lower socioeconomic status	Those who live in poverty or who have small body size are vulnerable to heat stress because of the potential for multiple exposures, poorer diets, and lack of access to medical care.
Pregnancy	Some individuals with underlying health conditions (who have weakened immune system by pregnancy, diabetes and autoimmune disease) may be more sensitive to molds.
Immunologic status	People who have human immunodeficiency virus infection or immunosuppressed as a result of cancer therapy or health hazards are more at risk for serious infections.
Type of work clothing	Workers required to wear semipermeable or impermeable protective clothing or PPE such as Tyvek suits, gloves, air-purifying respirators are at risk of heat disorders.
Genetic characteristics	Genetic host factors (e.g., hemochromatosis gene) that modify pathophysiological effects of particles may play a role in predicting susceptibility to air pollution. Heat shock proteins and some genes (i.e., C-reactive protein, ICAM-1, metallothionein, and cNOS) change expression with heat stress.

Source: Schulte and Chun: Climate Change and Occupational Safety and Health: Establishing a Preliminary Framework. J Occup Environ Hyg 2009. <https://doi.org/10.1080/15459620903066008>

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CDC's Building Resilience Against Climate Effects (BRACE) Framework

A five-step process that allows health officials to develop strategies and programs to help communities prepare for the health effects of climate change.

Part of this effort involves incorporating complex atmospheric data and both short and long range climate projections into public health planning and response activities.

Step 1: Anticipate Climate Impacts and Assessing Vulnerabilities

Identify the scope of climate impacts, associated potential health outcomes, and populations and locations vulnerable to these health impacts.

Step 2: Project the Disease Burden

Estimate or quantify the additional burden of health outcomes associated with climate change.

Step 3: Assess Public Health Interventions

Identify the most suitable health interventions for the identified health impacts of greatest concern.

Step 4: Develop and Implement a Climate and Health Adaptation Plan

Develop a written adaptation plan that is regularly updated. Disseminate and oversee implementation of the plan.

Step 5: Evaluate Impact and Improve Quality of Activities

Evaluate the process. Determine the value of information attained and activities undertaken.



<https://youtu.be/2PWPGI7NSUo>



<https://www.cdc.gov/climateandhealth/BRACE.htm>

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Take-home message

- Eco-anxiety and mental health problems following disasters are considered as major health problems related to climate change.
- Heatwaves increase the risk of mental health-related outcomes.
- Health care systems should be adapted to meet the increased demand for mental health services relating to climate change.
- Health care professionals experience the physical and mental health risks of climate change more acutely than the general population.
- People working outdoors or in hot indoor environments, or emergency responders are more vulnerable to the health impacts of climate change than the general population.
- Climate change may result in increasing the prevalence, distribution, and severity of known occupational hazards.

Must-to-read materials

- Coffey et al.: Understanding Eco-anxiety: A Systematic Scoping Review of Current Literature and Identified Knowledge Gaps. The Journal of Climate Change and Health 3 (2021) 1000472. <https://doi.org/10.1016/j.joclim.2021.100047>
- Liu et al.: Is there an association between hot weather and poor mental health outcomes? A systematic review and meta-analysis. Environ Int. 2021. <https://doi.org/10.1016/j.envint.2021.106533>
- Löhmus M.: Possible Biological Mechanisms Linking Mental Health and Heat – A Contemplative Review. Int J Environ Res Public Health. 2018. <https://doi.org/10.3390/ijerph15071515>
- Schulte and Chun: Climate Change and Occupational Safety and Health: Establishing a Preliminary Framework. J Occup Environ Hyg 2009. <https://doi.org/10.1080/15459620903066008>

Test your knowledge

- 1) What mental health effects can occur following disasters?
- 2) What is „Eco-Anxiety“?
- 3) Summarize the study results regarding hot weather (and related climate effects) and poor mental health outcomes!
- 4) What are the possible biological mechanisms which can link heat to poor mental health?
- 5) Who are most at risk of climate change related mental health problems?
- 6) How does climate change affect the health care system?
- 7) How does climate change affect the health of workers?
- 8) Which factors can increase susceptibility to climate-related occupational hazards?
- 9) What is the „BRACE“ Framework?

Thank you for you attention!

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Pharmacological aspects, medication

What are the major impacts of medication on the body's cooling mechanism?

- Medication can potentially cause increased health problems in a number of ways (WHO Regional Office for Europe, 2009); by:
 - altering central thermoregulation and therefore
 - physiological and behavioural responses;
 - changing cognitive alertness, leading to, for example,
 - increased drowsiness and reduced heat avoidance behaviour;

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Why are psychiatric patients at a very high risk-2?

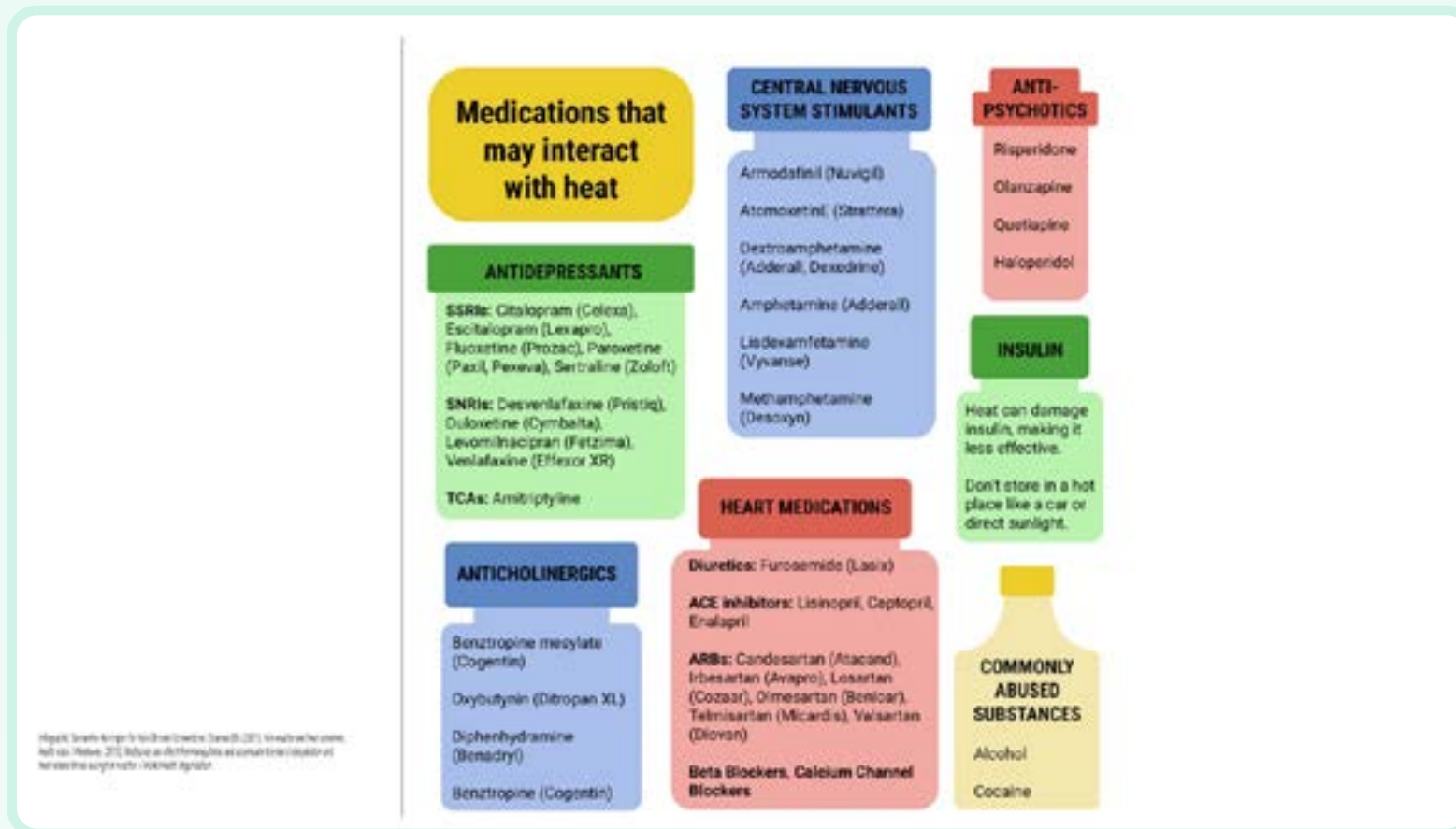
- Schizophrenic patients on antipsychotic therapies have a much lower heat tolerance, with a higher possibility of developing hyperthermic syndromes such as febrile catatonia or neuroleptic malignant syndrome.
- Antipsychotics have combined anticholinergic and central thermoregulatory effects. They can cause impairment of hypothalamic temperature regulation due to its antidopaminergic activity, which elevates the set point of temperature regulation centre.
- Moreover, they can also inhibit sweating. Both of these mechanisms lead to increased body temperature and higher risks of heat-related illnesses.

Why are psychiatric patients at a very high risk-1?

- Most psychotropic drugs have a substantial impact on body temperature regulation as a result of its numerous effects on the hypothalamus.
- Psychiatric patients are at great risk (three to four times higher incidence of heat-related deaths) of developing a heat-related illness, heat stroke.
- Two groups of psychiatric drugs, antipsychotics and antidepressants have a significant impact on body temperature regulation.

Adverse effects of medication at high temperature

- changing blood pressure and cardiac output, affecting cooling by vasodilation or increasing dizziness and fainting;
- inhibiting normal sweating mechanisms for cooling by evaporation due to anti-cholinergic effects blocking the parasympathetic nervous system;
- altering renal function and electrolyte balance, with increased risks from dehydration and drug toxicity, or overhydration and electrolyte imbalance



effect and can be worsened by excess fluid intake

- Reduce sweating, some can decrease centrally induced thermoregulation and cognitive alertness
- Reduce sweating and increase dizziness, decrease cardiac output and therefore reduce cooling by vasodilation, and worsen respiratory symptoms
- Can prevent dilation of the blood vessels in the skin, reducing the capacity to dissipate heat by convection
- Vasodilators, including nitrates and calcium channel blockers, can worsen hypotension in vulnerable patients
- Can lead to dehydration and reduce blood pressure; hyponatraemia is a common side effect and can be worsened by excess fluid intake

Medication

- Antidepressants
- Anxiolytics and muscle relaxants
- Antiadrenergics and beta-blockers
- Sympathomimetics
- Antihypertensives and diuretics

Mechanism

- Reduce sweating, some can decrease centrally induced thermo-regulation and cognitive alertness
- Reduce sweating and increase dizziness, decrease cardiac output and therefore reduce cooling by vasodilation, and worsen respiratory symptoms
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Pharmacons - mechanism of adverse effects

Effect of heat on medicines

- Temperature at storage
- Thermosensitivity of medicines
- Thermosensitivity of vaccines
- Pharmacons known to be photosensitive and heat sensitive
- The effect of medicines on thermoregulatory systems

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and eye drops should be protected from temperatures above 20°C, etc.

- It can be assumed that, especially in non-air-conditioned emergency units and wards, the effects and efficacy of the drugs are different from the „producer's description“.
- A general cooling of drugs is required, in contrary to general practice.

It is a misconception that solid phase drugs are not degradable.

Many pharmacological products act on receptors, in fact they act on families of receptors.

Even small changes in structure can have very different effects (e.g. a ligand binds irreversibly as a result of the change, etc.).

Therefore, heat reduces the drug content, changes the action, even causes unwanted side effects, and deteriorates the consistency of the drug

Temperatures in medical bags in ambulances can reach 40°C (or even more!) in summer.

The maximum storage temperature for medicines in general (and by no means for all medicines!) should not be more than 25°C.

Heat can also change the structure of carriers and active substances, sometimes leading to interactions between them.

Thermosensitivity of medicines:

- Compounds containing peptide bonds (e.g. staphostatins) are highly sensitive to high external temperatures

Some examples:

- Doxorubicin should be kept at 2-8 °C before use
- The active ingredients of nitroglycerine, bavacizumab, ritonavir, beta-blockers

Thermosensitivity of vaccines

- Since all vaccines, both viral and bacterial, are most stable at exactly 2-8 °C, providing adequate storage has turned out to be an immense challenge.
- In general, killed whole-cell bacterial vaccines, like pertussis vaccine, show a higher degree of stability of potency compared to live attenuated vaccines, such as BCG.
- However, when tested in high-temperature conditions, BCG vaccine has proven to be more stable than Pertussis vaccine.
- Also, diphtheria and tetanus toxoids have proven to be most stable during exposure to various conditions.

Stability of vaccines commonly used in national immunization programmes

World Health Organization: Temperature sensitivity of vaccines Immunization, Vaccines and Biologicals. 2006; 1-62.
<https://apps.who.int/iris/handle/10665/69387>

Type	Vaccine	Storage temperature, °C					
		2-8	20-25	37	>45	Freezing	
Viral vaccines	Oral poliovirus vaccine	Stable for up to 1 year	Stable for weeks	Stable for 2 days	Unstable	Stable	
	Inactivated poliovirus vaccine	Stable for 1-4 years	Stable for weeks	Stable for weeks	Little data available	Unstable	
	Hepatitis B vaccine	Stable for >4 years	Stable for months	Stable for weeks	At 45°C, stable for days	Unstable	
	Measles, mumps, rubella vaccines	Stable for 2 years	Stable for at least one month	Stable for at least one week	Unstable	Stable	
	Yellow fever	Stable for >2 years	Stable for months	Stable for two weeks	Unstable	Stable	
Bacterial vaccines	Pertussis vaccine	Stable for 18-24 months	Stable for 2 weeks	Stable for one week	10% or more loss of potency per day	Unstable	
	BCG vaccine	Stable for 1-2 years	Stable for months	Loss of no more than 20% after one month	Unstable	Stable	
	Tetanus and diphtheria toxoids, monovalent or components of combined vaccines	Stable for >3 years	Stable for months	Stable for months	Unstable above 55°C	Unstable	

Pharmacons known to be photosensitive and heat sensitive -1

- adrenaline, acetone, acryflavine, p-amino benzoic acid esters, p-amino salicylic acid, amobarbital, aneurine, apoeatropine, apomorphine, ascorbic acid, atropine,
- benzocaine, benzodiazepines, benzyl alcohol, benzyl nicotinate, benzyl maleate,
- erythromycin,
- neostigmine bromide, nicotinic acid, nicotinic acid amide, nifedipine, -cyrlic acid esters, nitrofurazone,

Pharmacons known to be photosensitive and heat sensitive - 2

- prednisone, prednisolone, progesterone, propyl gallate, piridoxine hydrochloride,
- reserpine, resorcinol, riboflavin,
- sorbic acid, streptomycin, strofantin, sulfonamides,
- testosterone, tetracaine, alpha-tocopherol acetate, triethanolamine,
- vanillin, waxes, xanthocillin, yohimbine

The effect of medicines on thermoregulatory systems

- Physiological responses to thermoregulation and heat shock can be affected by a range of drugs, from cellular regulation to systemic responses
- The affected targets are:
 1. heat shock proteins
 2. vascular regulation
 3. sudatio (sweating)
 4. thermogenesis, rate of metabolism
 5. fluid and ion balance

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Be careful with drugs that affect the central nervous system!

A particular danger of psychoactive agents is that they impair insight, may cause sleepiness, distraction.

- Alcohol has a similar effect, mainly hypothermia and risk of freezing in vagabonds, homeless people, but also increases the risk of hyperthermia (falling asleep in the sun).
- Psychoactive drugs such as selective serotonin reuptake inhibitors (SSRIs), monoamine oxidase inhibitors (MAOs) and tricyclic antidepressants can cause hyperthermia.

→ Hyperthermia can occur as an additive effect of many illegal drugs such as amphetamines, cocaine, PCP, LSD and MDMA.

Malignant hyperthermia is a relatively rare reaction of the body to anaesthetic substances (e.g. halothane) or muscle relaxants (e.g. succinylcholine).

Amphetamine effect

Disco drugs, young people likely to collapse while dancing

Signs of 3,4-methylenedioxymethamphetamine (MDMA), „ecstasy“ intoxication:

- Unconsciousness
- Tachyarrhythmia
- Seizures
- Pupillary dilation
- Hypertension
- Acidosis
- Muscular rigidity
- Hyperthermia
- Sudatio

The effect of medicines on thermoregulatory systems

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Vascular factors

- An important element of thermoregulation is vasodilatation of peripheral blood vessels, acra and skin and skin appendages.
- Increased peripheral blood flow helps dissipate heat and sudation.
- However, this effect is impaired in a state of actual shock due to centralisation of the circulation.
- The blood vessels receive 1 stimulation and respond to this stimulation or to bradykinin by vasodilation;
 - but anticholinergics effectively reduce parasympathetic tone, thus

reducing heat dissipation by inducing centralisation of the circulation.

Many substances having anticholinergic, parasympathetic tone-lowering effects

- also centralise the circulation,
- reduce sweat gland secretion,
- increase cardiac work and heat production, and

→ act directly on the CNS thermoregulatory center in the hypothalamus, producing a dose-dependent symptomatology of vagal lysis

Other additional impacts

- The signs of *atropine and scopolamine poisoning* are not accidentally hyperthermia, the main cause is a CNS effect, but the above factors certainly aggravate it, and
- in the case of external temperatures higher than thermoneutral, an important side effect of these drugs is that they reduce the ability to adapt to heat (further unfavourable impacts on urination, dry throat, thirst in hyperthermia).
- *Diphenhydramine (Benadryl™)* has antihistamine and anticholinergic effects, and may also induce a photoallergic reaction in addition to inhibiting sweat gland secretion.

Substances that inhibit sudatio

- Tricyclic antidepressants (TCAs) also inhibit sweating through their anticholinergic action.
- The following substances are antiperspirants with proven anticholinergic activity (besides antihistamine and dopamine receptor blocking activity):
 - Out of the phenothiazines chlorpromazine (Thorazin™), fluphenazine (Prolixin™); out of the butyrophenones haloperidol (Haldol™)
 - Out of the atypical antidepressants clozapine (Clozaril™), risperidone (Risperdal™), olanzapine (Zyprexa™).
- They are also associated with typical atropine-like symptoms in overdose: flushing, dry mouth, warm sensation, intestinal and bladder paralysis
- Overdosing with MAO paralyzers leads to hyperpyrexia, seizures, coma.

Increasing heat production

- The β 2-receptor stimulating agents have already been mentioned
- Stimulants such as *cocaine and amphetamine* - in addition to faster heart rate, increased muscle activity and accelerated metabolism etc., they also have a direct effect on the thermoregulatory center (hypothalamus) resulting in an increase of body temperature.
- It is also a well-known effect that *amphetamines* cause severe dry mouth and thirst (which is exploited in some nightclubs by turning off the taps - more than one death has been caused by this "practice").

Increasing heat production

- Not only 'illegal', but also drugs used in medicine or in consumer practice, such as *theophylline*, *caffeine*, have similar (but usually milder) effects.
- For the above reasons, the consumption of strong black coffee during hot flushes is strongly contraindicated, especially for people working in the hot sun or for elderly, polymorbid persons, and the use of any stimulant drugs should also be considered.

Fluid and ionic balance

- Diuretics, in particular the ion-losing (especially K⁺) diuretic agents hydrochlorothiazide (HCTZTM), furosemide (LasixTM) also lead to dehydration by increasing renal salt and water excretion.
- Ethyl alcohol reduces ADH secretion, but at the same time increases the level of atrial natriuretic peptide (ANP), thereby increasing the rate of diuresis and decreasing adequate behaviour and insight.

Pharmacokinetics

- Metabolic processes are most likely linearly (rather slightly exponentially) related to temperature up to the point where the proteins involved in metabolism start to denature.
- In the liver, drug degradation is faster at higher core temperatures.
- Changes in renal and hepatic functions during heat stress (reduced blood volume to kidney, liver) also slow down the degradation and elimination of pharmacologic compounds.

Other impacts

- Antipyretics are not effective in reducing high body temperature related to heat. They lower the body temperature only when thermoregulation has been raised by pyrogens. Their use may be harmful in treating heat related illness due to their renal and hepatic side effects.
- Many drugs may cause diarrhoea and vomiting as a side effect and may lead to an increased risk of dehydration in hot weather.

Special problems in elderly patients

- Various drug classes associated with hyperthermia are used more in the age group ≥ 60 years, referring to polypharmacy in the elderly as a contributing factor for hyperthermia.
- In a study *antiepileptics* and *furosemide* were the most frequently used drugs in patients with primary hyperthermia. The high use of levothyroxine in the study population was also an interesting findings.

Source: Bongers KS, Salahudeen MS, Peterson GM. Drug-associated hyperthermia: A longitudinal analysis of hospital presentations. doi: 10.1111/jcpt.13090.

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Some interesting findings

- A study demonstrated a correlation between blood flow and transdermal absorption of nitroglycerin by locally heating nitroglycerin patches placed on multiple areas of the upper arm.
- Results after heating for 15 minutes were enhanced local blood perfusion and simultaneously significantly increased nitroglycerin plasma concentrations. Therefore, using the percutaneous form of nitroglycerin could lead to an additional decrease in blood pressure during warm weather.

Source: Šklebar T, Rudež KD, Rudež LK, Likić R. Global Warming and Prescribing: A Review on Medicines' Effects and Precautions. *Psychiatr Danub*. 2022 Dec;34(Suppl 10):5-12. PMID: 36752238.

Some interesting findings

- Taking injected insulin subdermally could create a severe hypoglycemia in diabetic patients. The elimination of drugs with high hepatic extraction rates is affected by changes in hepatic blood flow.
- Increased skin blood flow can, as a result, have decreased blood flow to the internal organs and therefore reduced hepatic clearance of drugs.

Šklebar T, Rudež KD, Rudež Likić R. Global Warming and Prescribing: A Review on Medicines' Effects and Precautions. Psychiatr Danub. 2022 Dec;34(Supl 10):5-12. PMID: 36752238.

Recommendations for healthcare professionals to reduce the risk of dehydration and heat-related illness -1

Review the patient's medicines.

- 1.) During hot weather, it is even more important to apply the general principles of using the **lowest effective dose for the shortest possible time.**
- 2.) People prescribed a psychotropic medicine are at a particularly high risk because of both the effect of their illness on behaviour and the medicines they take.
 - It is especially important for people on psychotropics to have the dose reviewed and for them to have an awareness of the risks of heat-related illness and knowledge of the protective measures they can take.

Recommendations for healthcare professionals to reduce the risk of dehydration and heat-related illness - 2

- 3.) If practical, delay initiating or increasing the dose of a psychotropic medicine until the hot weather is over.
- 4.) If prescribed a diuretic, consider dose reduction during hot weather if appropriate. An individualized plan for the patient to adjust their diuretic medicine themselves on hot days can be useful.

Recommendations for healthcare professionals to reduce the risk of dehydration and heat-related illness- 3

- 5.) If on fluid restrictions, consider whether relaxing the restrictions during periods of hot weather is appropriate.
- 6.) When combinations of medicines, such as a diuretic and ACE inhibitor or ARB, are initiated during hot weather, they may increase the risk of hypovolaemia and dehydration. Consider initiation of the diuretic at a lower dose, if possible.
- 7.) A review of an older person's medicines by an accredited pharmacist either in their home, if living independently, or in an aged care facility, if a resident there, may be prudent. Provide counselling about how to stay well and store medicines safely during hot weather.

Take home message - 1

Medications + Hot Weather Can Create Risks

Prescription medications can affect the body's response to extreme heat in a number of different ways. Some of the major mechanisms at play:

inside
climate
news



SOURCE: ICN research

PAUL HORN / InsideClimate News

Take home message

- Healthcare professionals should be aware of the increasing prevalence of hyperthermia and the possible involvement of drugs.
- Some classes of medications commonly used by older patients with chronic conditions may predispose these individuals to heat-related complications.
- These medications can sensitize a patient to heat by disrupting thermoregulatory responses that maintain core body temperature, either by interfering with cognitive processes or by directly disrupting autonomic mechanisms.



<https://nexusmedianews.com/prescription-drugs-and-extreme-heat-a-deadly-combination-bbbfe4a68a49/>

Take-home messages

- Thermoregulation may be affected by numerous centrally-acting medications for neuropsychological disorders including antipsychotics, beta blockers, stimulants, and a broad array of medications with anticholinergic properties.
- Dehydration with or without concurrent electrolyte disturbance may also contribute to thermoregulatory failure, and medications that suppress thirst and disrupt fluid balance such as angiotensin converting enzyme (ACE) inhibitors and diuretics, are commonly used by older patients with chronic conditions.

Thank you for you attention!

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The Impact of Climate Change on Vector-Borne Diseases and Other Infections

1. Introduction

- World Health Organisation (WHO): approximately one sixth of worldwide disability and illness is due to vector-borne diseases (VBDs).
- Annually, VBDs infect over one billion people and kill more than a million, in addition to curtailing socioeconomic development and placing considerable strain on health services.
- The high sensitivity of VBDs to climate and weather conditions, in particular temperature, humidity, and precipitation, result in a complex interplay between these factors and the pathogenesis, propagation, and societal impact of these diseases.
- In the context of this lesson, we will examine the current state of knowledge on this topic, and survey practical approaches to counteract and alleviate the effects of climate change on VBDs and related diseases.



2. Learning Outcomes

Upon successful completion of the lesson, students will be able to:

- ✓ Develop an understanding of the major vector-borne diseases in terms of their pathogens, vectors, reservoir hosts and general clinical features.
- ✓ Discuss the environmental and other stressors that influence infectious disease pathogenesis and propagation.
- ✓ Assess the effects of recent global change drivers that are pertinent to disease emergence, local-scale dynamics and global spread of vector-borne diseases.
- ✓ Survey and analyse the current literature, using on-line interactive tools, to maintain an up-to-date knowledge of vector-borne diseases that are aggravated by climate change.
- ✓ Critique, for individual vector-borne diseases, the effects predicted from the latest climate change data and modelling results.
- ✓ Understand and evaluate the control methods for the prevention and mitigation of vector-borne disease epidemics caused by climate change.

3.2 Major vector-borne diseases

Disease	Pathogen	Vector(s)	Non-human reservoir hosts	Clinical Features in Untreated Cases
Babesiosis	<i>Babesia microti</i> parasite	<i>Ixodes scapularis</i> (Deer ticks)	White-footed mouse, other small mammals.	Flu-like symptoms, destruction of red blood cells, jaundice, blood clots/bleeding, vital organ malfunction, death.
Bubonic plague	<i>Yersinia pestis</i> bacteria	Fleas	Rodents	Inflamed lymph nodes, infection of lungs giving pneumonic plague, death.
Chagas disease (American trypanosomiasis)	<i>Trypanosoma cruzi</i> parasite	Triatomine bug	Mammals	Skin lesions, cardiac, digestive or neurological disorders, heart failure, death.
Chikungunya	Alphavirus	<i>Aedes</i> mosquitoes	None of concern	Fever, rash, joint swelling, muscle pain, premature death in newborns and older people with underlying health conditions.
Crimean-Congo haemorrhagic fever	Bunyaviridae nairovirus	Ticks	Wild and domestic animals, ostriches.	Kidney, liver or pulmonary failure.
Dengue fever	Dengue flavivirus	<i>Aedes</i> mosquitoes	None of concern	Internal bleeding, shock, death.
Hookworm infection	<i>Bulinus globosus</i>	Snail	Dogs, cats.	Rash, anaemia, abdominal pain, diarrhoea.
Japanese encephalitis	Japanese encephalitis flavivirus	<i>Culex</i> mosquitoes	Pigs, birds.	Fever, disorientation, coma, seizures, spastic paralysis, death.
Leishmaniasis	<i>Leishmania</i> parasite	Sand fly	Rodents, dogs, other mammals.	Skin lesions, destruction of mucous membranes, spleen/liver enlargement, death.
Lyme disease	<i>Borellia spirochete</i> bacteria	<i>Ixodes</i> ticks	White-footed mouse, other small mammals, birds.	Fever, facial palsy, arthritis, inflammation of brain/spinal cord, nerve pain.
Lymphatic filariasis	Various filarial nematodes (roundworms)	Various mosquito genera	None of concern	Lymphatic, kidney and immune system damage, tissue swelling, elephantiasis.
Malaria	<i>Plasmodium</i> parasite	<i>Anopheles</i> mosquito	None of concern	Organ failure, blood, metabolism or neurologic abnormalities, acute respiratory distress, kidney injury, cardiovascular collapse, relapses, death.

Major vector-borne diseases (contd.)

Disease	Pathogen	Vector(s)	Non-human reservoir hosts	Clinical Features in Untreated Cases
Onchocerciasis (river blindness)	<i>Onchocerca volvulus</i> nematode	<i>Simulium</i> (blackfly)	None	Eye lesions, severe skin inflammation, blindness.
Rift Valley fever	RVF virus	<i>Aedes</i> and <i>Culex</i> mosquitoes	Sheep, goats, other domesticated animals.	Eye disease, meningoencephalitis, haemorrhagic fever.
Schistosomiasis (bilharziasis)	<i>Schistosoma</i> trematode flukes (flatworms)	Snail	None of concern	Intestinal/urogenital pathologies, liver or spleen enlargement, infertility, kidney failure, bladder cancer, ectopic pregnancies, death.
Sleeping sickness (African trypanosomiasis)	<i>Trypanosoma brucei</i> parasite	<i>Glossina</i> (tsetse fly)	Wild and domestic animals	Fever, joint pains, central nervous system disorders, death.
Tick-borne encephalitis	Flavivirus	<i>Ixodes</i> ticks	Small rodents	Fever, central nervous system disorders, paralysis, permanent sequelae, death.
Toscana virus infection/sand fly fever	Toscana phlebovirus and papataci fever virus	Sand flies	None known at present	Fever, headache, rash, vomiting, fatal encephalitis in rare cases.
Tungiasis	<i>Tunga penetrans</i> (sand flea)	Sand flea	Pigs, bovines, dogs, cats, rats.	Abscesses, bacterial superinfection, disfigurement.
Typhus	Rickettsial bacteria	Fleas, mites, ticks, lice	Rodents, opossums, feral cats	Fever, headache, rapid breathing, body & muscle pain, cough, vomiting.
West Nile fever	Flavivirus	<i>Culex</i> mosquitoes	Birds	Fever, coma, tremors, convulsions, paralysis.
Yellow fever	Flavivirus	<i>Aedes</i> mosquitoes	Non-human primates	Fever, jaundice, bleeding, organ failure, death.
Zika	Flavivirus	<i>Aedes</i> mosquitoes	None of concern	Fever, rash, joint & muscle pain, conjunctivitis.

4. Environmental and other stressors that influence disease pathogenesis and propagation

4.1 General considerations

Over the past couple of decades the global landscape of infectious disease risk has been altered by a number of factors, both aggravating and diminishing in terms of disease pathogenesis and propagation.

- *Anthropogenic climatic*: change in climate caused by the activities of mankind. Primarily global warming induced by increased levels of greenhouse gases.
- *Demographic*: factors such as increased urbanization, population growth, land-use change, migration, ageing, and changing birth rates.
- *Technological*: changes caused by cheaper, faster global travel, increased international trade, and improved health care.

These three groups of stressors do not act independently, but are interlinked in often complex and poorly understood ways.

We can consider the impacts of these stressors in terms of their effects on disease emergence (pathogenesis) into human populations, local-scale disease dynamics, and global spread.

4.2 Pathogenesis

The following steps are necessary for a novel pathogen to become a threat:

1. Contact between humans and the animal reservoir must occur.
2. The pathogen must either have or evolve the capacity for human-to-human transmission.
3. Finally, this human-to-human transmission must enable expansion of the pathogen's geographical range beyond the zone of spillover.

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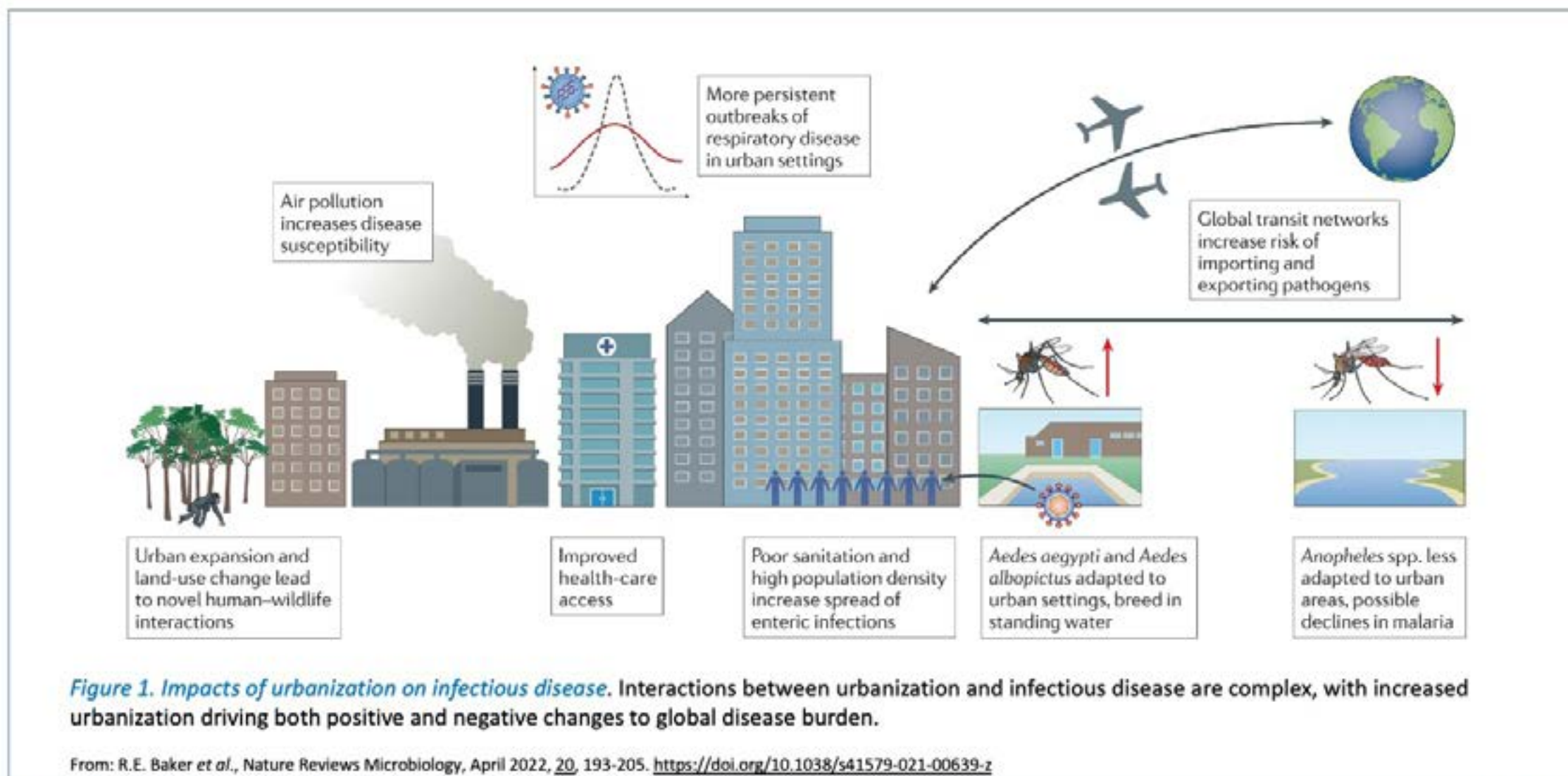
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Recent global changes affecting pathogenesis:

- Increased patterns of contact between human and wildlife reservoirs.
- Behaviours that increase the potential for spillover, such as consumption of wild meat.
- Intensifying contact between wild and domestic animal hosts.
- Expanding agriculture and its intensification.
- Changing nature of human populations that are exposed to potential spillover.
- Globally ageing populations with poor immune systems at risk of spillover.
- Evolutionary selection for drug resistance.

Climate change may play a role in the risk from pathogen spillover. Changing environmental conditions can alter species range and density, leading to novel interactions between species, and increase the risk of zoonotic emergence.

- Rapid **rates of urbanization** in low-income and middle-income countries.



4.3 Local-scale disease dynamics

Emerging, re-emerging and endemic pathogens in human populations may exhibit distinct dynamic patterns of spread at the local scale. These patterns will be governed by demographic factors, including:

1. Effects of **human behaviour** on transmission, e.g. school terms drive transmission of many childhood infections.
2. **Immunity**: shaped by replenishment of susceptible individuals via births, and depletion by vaccination.
3. Transmission may also be affected by **climatic variables** acting spatially or over the course of the year.

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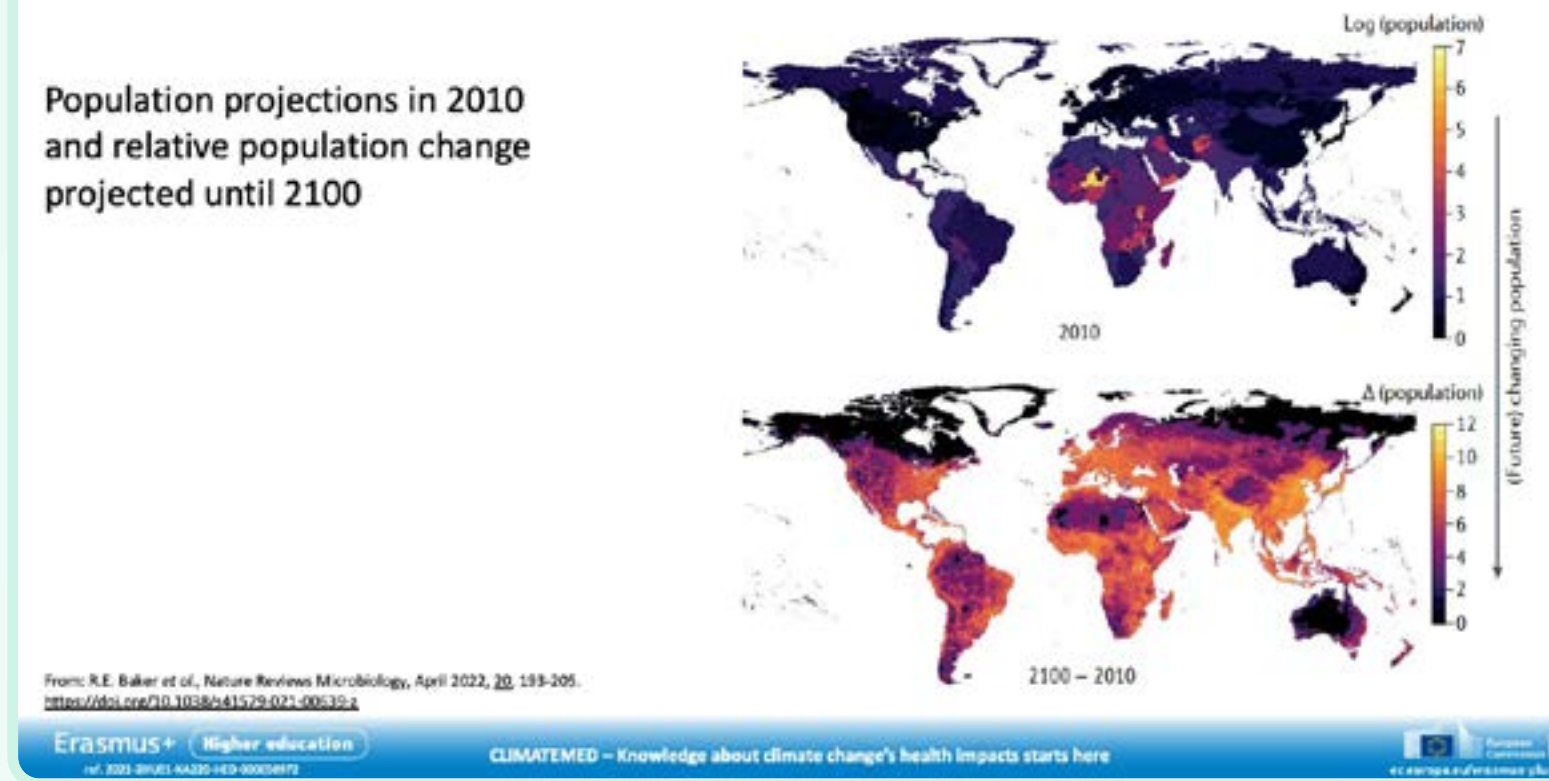
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Recent global changes have affected each of these drivers of local-scale dynamics:

- School attendance not only modulates transmission of childhood infections but also shapes human mobility.
 - Age specificity of the burden of disease.
 - Demographic changes to population size and density via urbanization may also affect dynamics.
 - Changes in the occurrence of immunomodulatory infections, which, in turn, may affect other infections.
 - Global change in climatic conditions will play a key role in driving the local-scale seasonal disease dynamics.
- Exposure to local air pollution in rapidly urbanizing locations, e.g. PM2.5 airborne microparticulates.
 - Living in an urban location may bring benefits in terms of increased access to health care.

Figure 2. Mapping changes to a demographic stressor: projected population changes



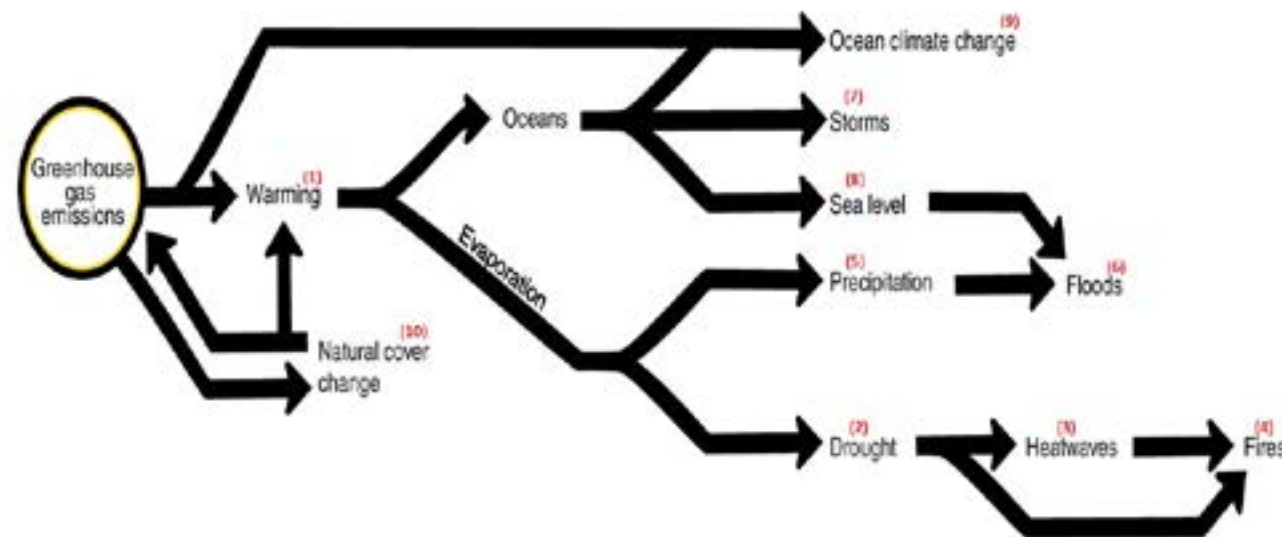
Demographic change and technological changes may alter a host's interaction with the environmental disease reservoir, e.g. improved sanitation can lower the risk of exposure to diseases such as cholera.

For VBDs, biological traits of both the vector and the pathogen may be sensitive to climate. Many transmission-related life cycle traits of the mosquito (biting rate, adult lifespan, population size and distribution) and the pathogen (extrinsic incubation rate) are temperature sensitive, and oviposition patterns depend on water availability.

Vaccination. At the local scale, one of the strongest footprints detectable on the dynamics of many endemic infections in recent

years is declines in incidence associated with access to vaccinations.

Figure 3. Climatic hazards of the Earth's system affected by the ongoing emission of Greenhouse Gases (GHGs).



From: C. Mora et al., Nature Climate Change, September 2022, 12, 869–875, <https://doi.org/10.1038/s41558-022-01826-1>

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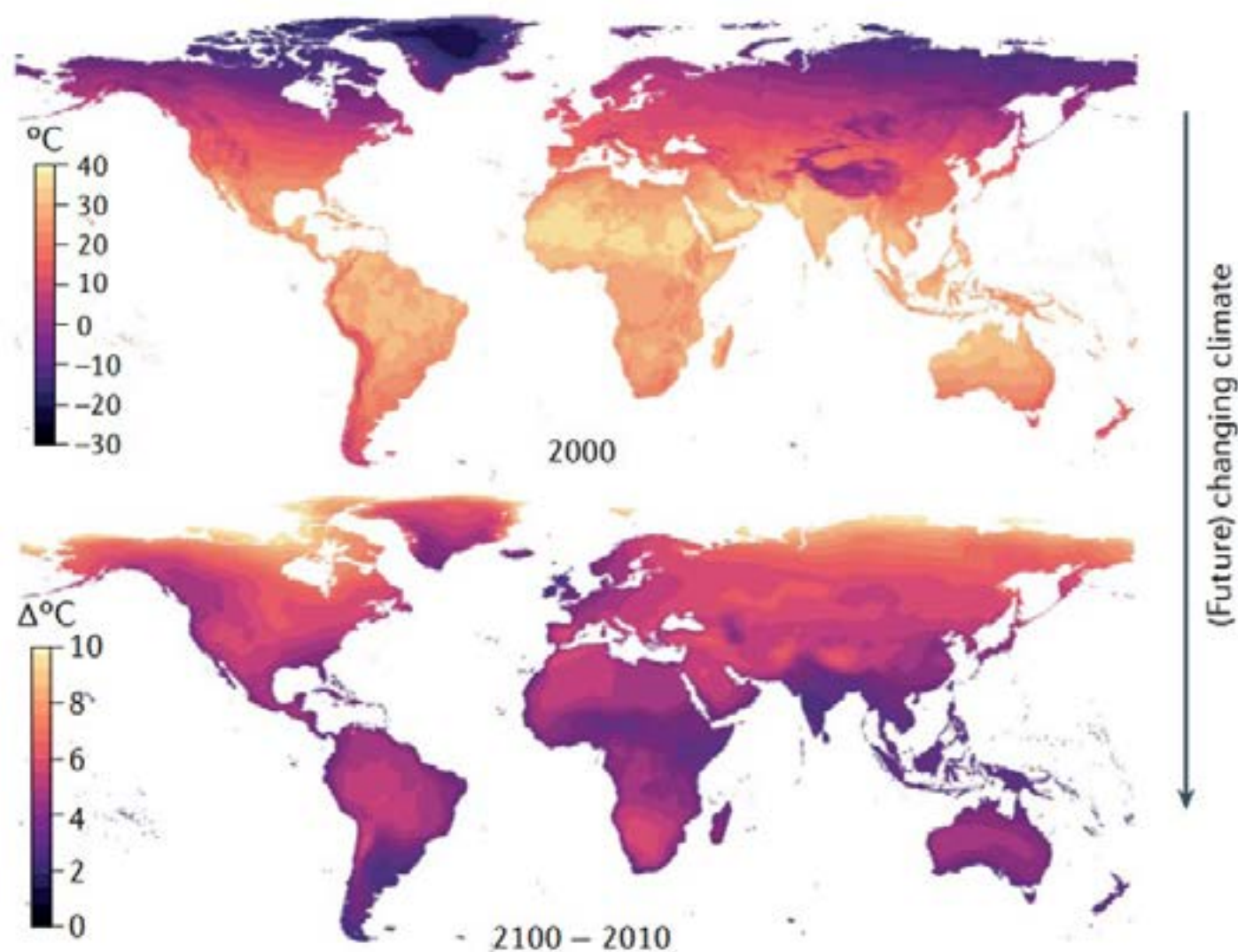
GHGs mediate the balance between incoming solar radiation and outgoing infrared radiation; thus, **(1)** their excess in the atmosphere causes warming. Compounded with an increased capacity of the air to hold water, warming accelerates soil water evaporation, leading to **(2)** drought in places that are commonly dry; excess drought can lead to **(3)** heatwaves. These ripen the conditions for **(4)** wildfires. In moist places, the quick replenishment of evaporation strengthens **(5)** precipitation, causing **(6)** floods. Warming of the oceans enhances evaporation and wind speeds, intensifying the strength of **(7)** storms, whose surges can be aggravated by **(8)** sea level rise. Uptake of CO₂ in the oceans causes ocean acidification, whereas changes in ocean circulation and warming reduces oxygen concentration in

seawater, leading to **(9)** ocean climate change. Change in natural land cover **(10)** can be a direct emitter of GHGs via deforestation and respiration, temperature modification via albedo* and evapotranspiration, and because it can be a direct modifier in the transmission of pathogenic diseases.

*The fraction of light that the earth's surface reflects back into space.

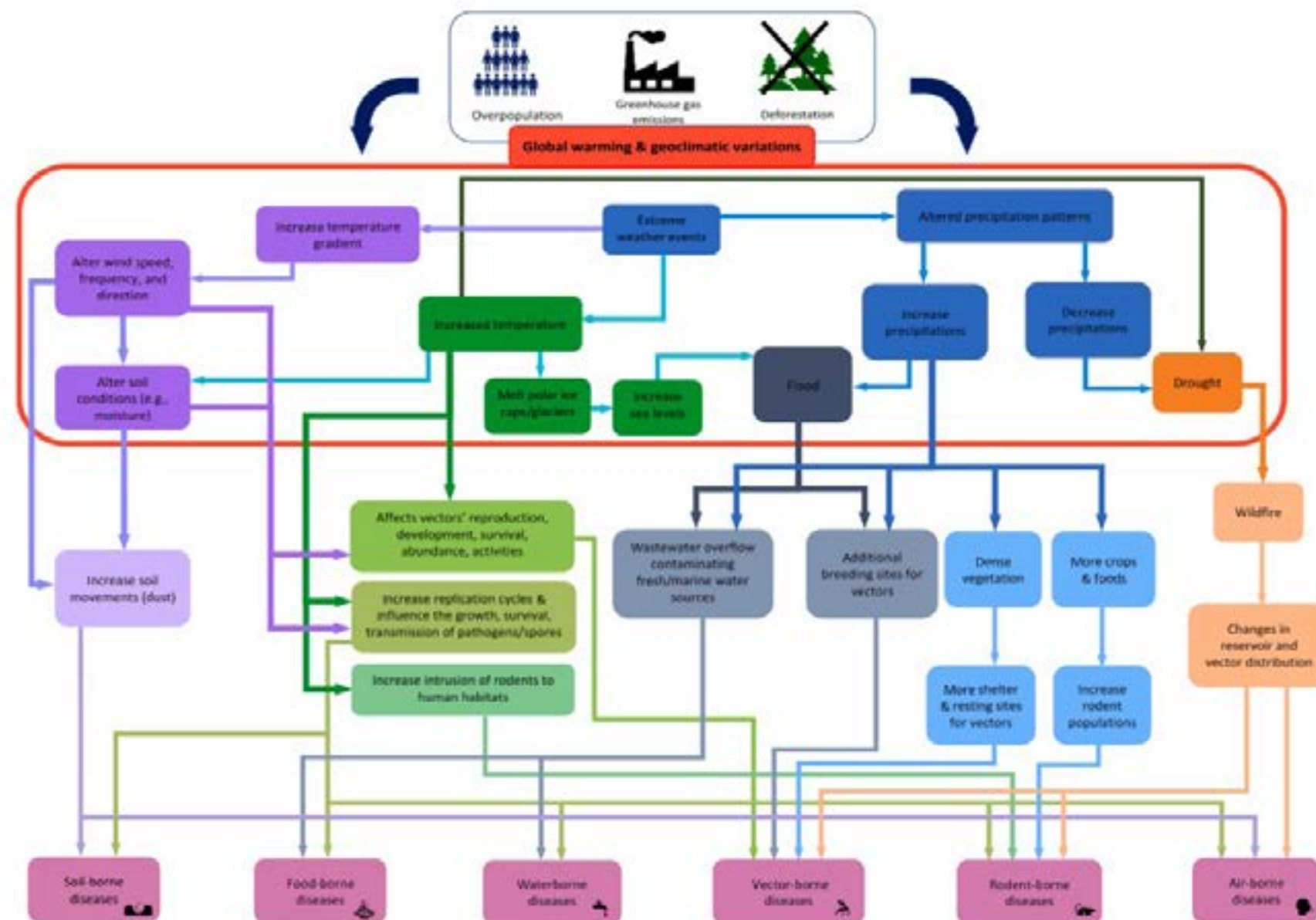
Figure 4. Mapping changes to an anthropogenic climatic stressor: average monthly maximum temperature changes

Average monthly maximum temperature in 1970–2000) and predicted difference between 2070–2100 and 1970–2000 averages.



From: R.E. Baker *et al.*, Nature Reviews Microbiology, April 2022, 20, 193–205.
<https://doi.org/10.1038/s41579-021-00639-z>

Figure 5. Impacts of global warming and geoclimatic variations on zoonoses.



From: R. Rupasinghe, B. B. Chomel, and B. Martínez-López, *Acta Tropica*, 2022, 226, 106225.
<https://doi.org/10.1016/j.actatropica.2021.106225>

Table 1. Environmental effects of global change drivers pertinent to vector-borne diseases.

Global change driver	Potential effects on vector, pathogen, and host environments	Potential effects on vectors, pathogens, and hosts
Higher CO ₂ concn	Increased ambient temperature and plant biomass; range expansion of woody vegetation; longer plant growth season with humid microclimates	Increased vector longevity for the same rainfall and temperature through more humid microclimates, with possible range expansion of humid-zone vectors
Temperature increase (regional/temporal variation)	Expansion of warm climatic zones, with longer growth seasons, less extreme low temperatures, and more frequent extreme high temperatures	Faster vector and pathogen development, with more generations per year; shorter life spans of vectors at high temperatures, reduced low-temperature mortality of vectors, and range expansion of warm-climate vectors and pathogens
Rainfall	Too uncertain and regionally variable to estimate, but increased frequency of extreme rainfall events	Altered patterns of breeding of mosquitoes, with more flushing of mosquito breeding with increased flooding
Urbanization	Increased density of human hosts, with poorer sanitation and water supply in developing countries Increased outer urban development in or near forests in developed countries	Higher rate of disease transmission at same vector density; more vector-breeding sites Increased contact between humans and vectors in periurban forested areas
Deforestation	Increased human entry into forests and increased surface water from soils exposed by logging or new agriculture	More vector-breeding sites and more contact between humans and vectors
Irrigation and water storage	Increased surface water, prevention of seasonal flooding	More vector-breeding sites; reduced flushing of snails and mosquitoes
Intensification of agriculture	Increased disturbance of land and vegetation and increased surface water; reduced biodiversity	More diversity of vector breeding sites, with reduced predation of vectors
Chemical pollution	Fertilizer, pesticide, herbicide and industrial toxins and endocrine-disrupting chemicals	Impaired human immune systems
Increased trade	Increased volume of shipped goods	Increased transport of vectors, leading to "homogenization" of vectors in receptive areas
Increased travel	Increased movement of people between North and South and East and West	Increased transfer of pathogens between regions of endemicity and disease-free regions, and increased exposure of visitors to regions of endemicity

From: R.W. Sutherst, *Clinical Microbiology Reviews*, Jan. 2004, **17**, (1), 136–173.
<https://doi.org/10.1128%2FCMR.17.1.136-173.2004>

4.4 Global spread

When considering the impact of global change on infectious disease risk, the effects of three forms of global connectivity can be considered:

1. International travel.
2. Human migration and local-scale mobility.
3. The international trade of animals, animal products and plants.

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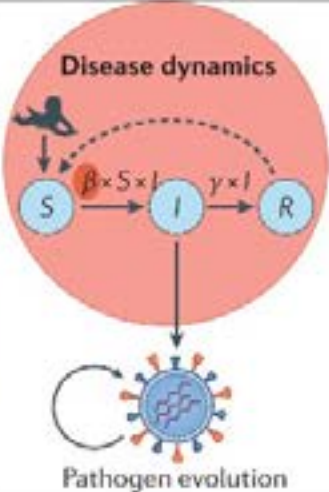

1. International travel. The total number of airline passengers doubled from just below two billion in 2000 to more than four billion in 2019. This step increase in global connectivity brings with it new risks from emerging and endemic pathogens that can circulate via transit routes. For example seasonal influenza circulation in the USA can already be predicted by flight patterns.
2. Human migration and local-scale mobility. It is estimated that globally the number of permanent international migrants is almost 272 million, representing 3.5% of the world's population. The rate of migration continues to increase owing to social, economic, political and environmental drivers. Climate change sea level rise and extreme weather will likely provide an escalating push factor in this respect.
3. The international trade of animals, animal products and plants. This has expanded rapidly in the modern era and has been matched by a global proliferation of infectious diseases affecting not only humans but also animals and plants. Trade drives this pattern by facilitating the translocation of hosts and pathogens across the geographical and ecological boundaries that constrain their spread.

4.5 Summary

Figure 6. Effects of climatic, technological and demographic change on disease emergence, dynamics and spread.

The table summarizes select recent global changes (rows) and their impacts on disease emergence, local-scale dynamics and global spread (columns).

An example susceptible (S), infected (I), recovered (R) model is shown, where β represents the transmission rate and γ is the recovery rate.

	 Pathogen emergence	 Disease dynamics Pathogen evolution	 Global spread
Climatic change	Drives range shifts for reservoir species	Affects transmission and susceptibility	Affects the geographical range of vectors
Technological change			
Transportation	Improved global surveillance		Air transit and high-speed rail affect pace and range of spread
Health care		Vaccination affects dynamics	Improved care reduces burden
Demographic change			
Population growth and land use	Increased contact with reservoir species	Population numbers affect evolution, birth rates affect dynamics	Larger population travelling
Urbanization	Depends on species	Density affects contact rate	Urban population more connected
Ageing	Immunosenescence affects spillover risk	Ageing population increases transmission	Possible larger burden

From: R.E. Baker et al., Nature Reviews Microbiology, April 2022, 20, 193-205.
<https://doi.org/10.1038/s41579-021-00639-z>

5. Current state of knowledge on the effects of climate change on the impacts, pathways, and interactions of VBDs on/with global societies

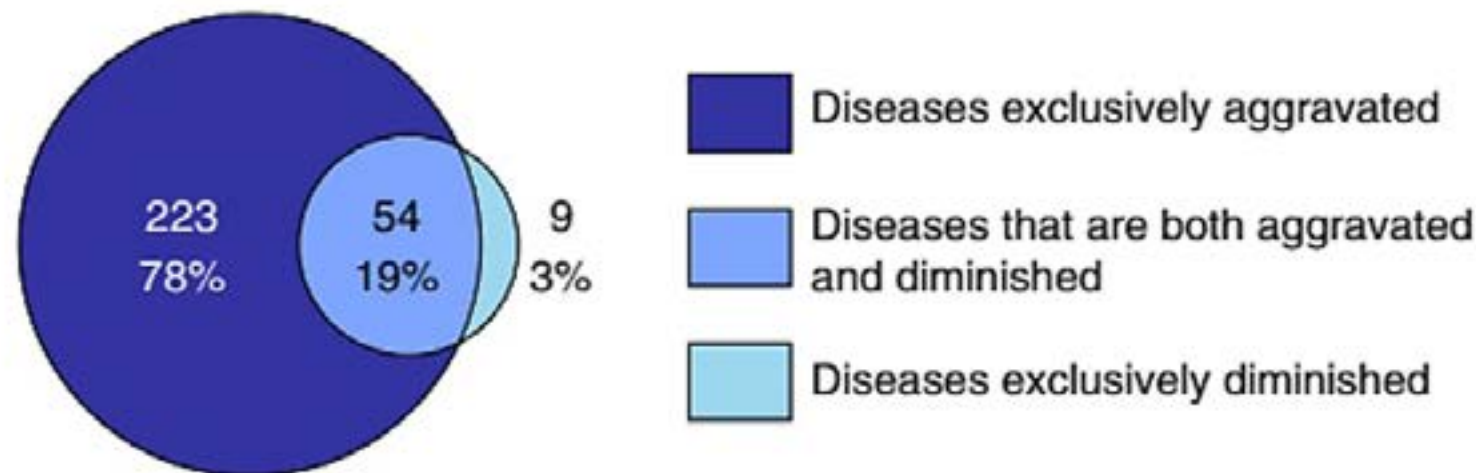


Figure 7. Discrimination of pathogenic diseases between those aggravated and diminished by climatic hazards

From: Mora C., McKenzie T., Gaw I.M., Dean J.M., von Hammerstein H., Knudson T.A., Setter R.O., Smith C.Z., Webster K.M., Patz J.A., and Franklin E.C., "Over half of known human pathogenic diseases can be aggravated by climate change", Nature Climate Change, September 2022, **12**, 869-875. <https://doi.org/10.1038/s41558-022-01426-1>

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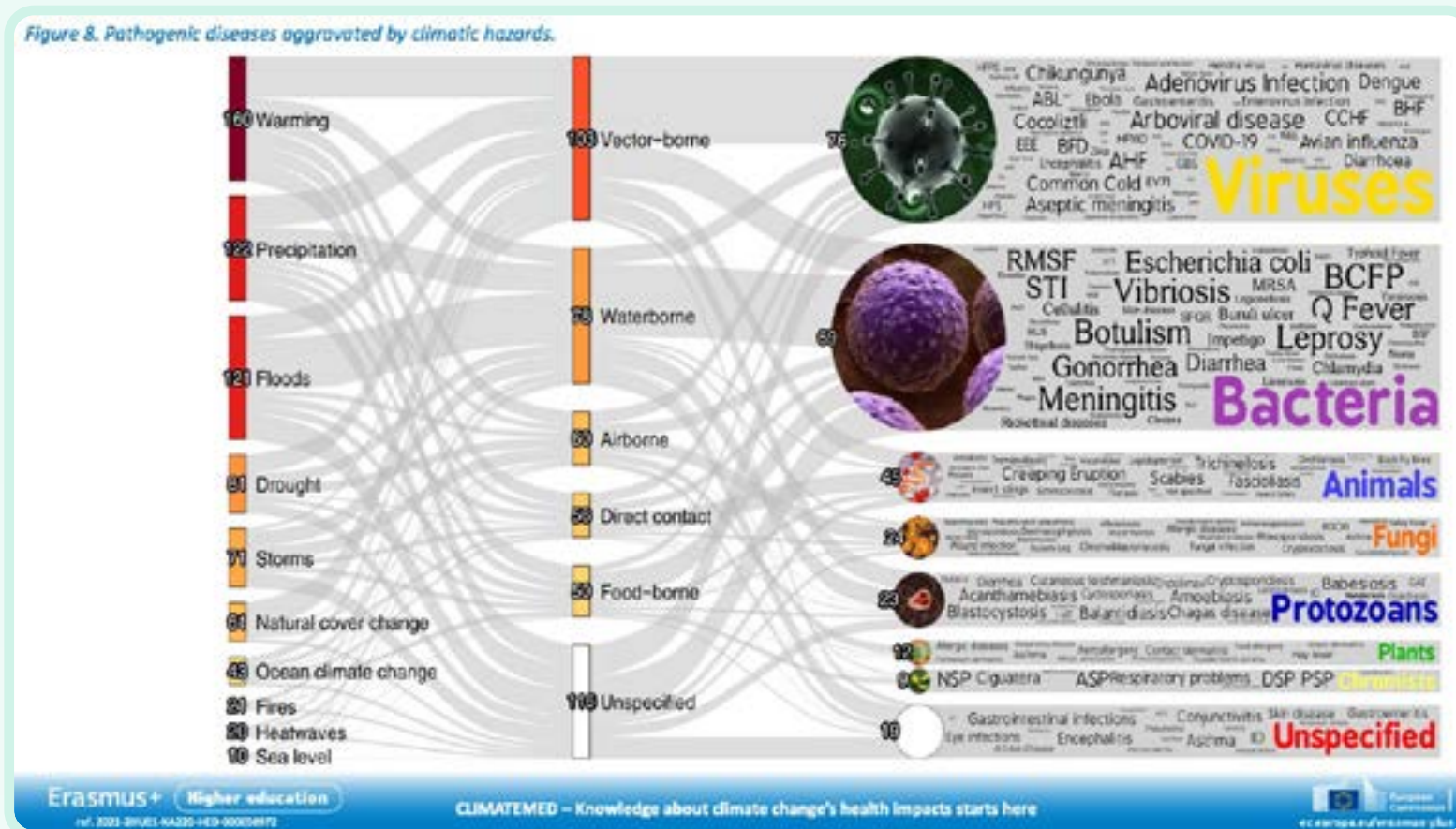
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5.1 Overview

It should be evident from section 4 that the environmental stressors that influence disease are numerous, complex, and often interlinked. When we overlay these on the large number of known infectious diseases, the possible effects of climate change on disease are very

numerous indeed. A recent review by Mora et al., found 3,213 cases in which the ten climatic hazards, listed in figure 3 section 4.3 above, were implicated in a total of 286 pathogenic diseases. The vast majority of these showed disease aggravation.



Mora et al. have also presented a useful summary visualisation (figure 8 below) of their results, also available on-line for detailed interactive interrogation at

→ <https://camilo-mora.github.io/Diseases/>

Displayed here are the pathways in which climatic hazards, via specific transmission types, result in the aggravation of specific pathogenic diseases. The thickness of the lines is proportional to the number of unique pathogenic diseases. The colour gradient indicates the proportional quantity of diseases, with darker colours representing larger quantities and lighter colours representing fewer. Numbers at each node are indicative of the number of unique pathogenic diseases.

Some general observations can be made from figure 8:

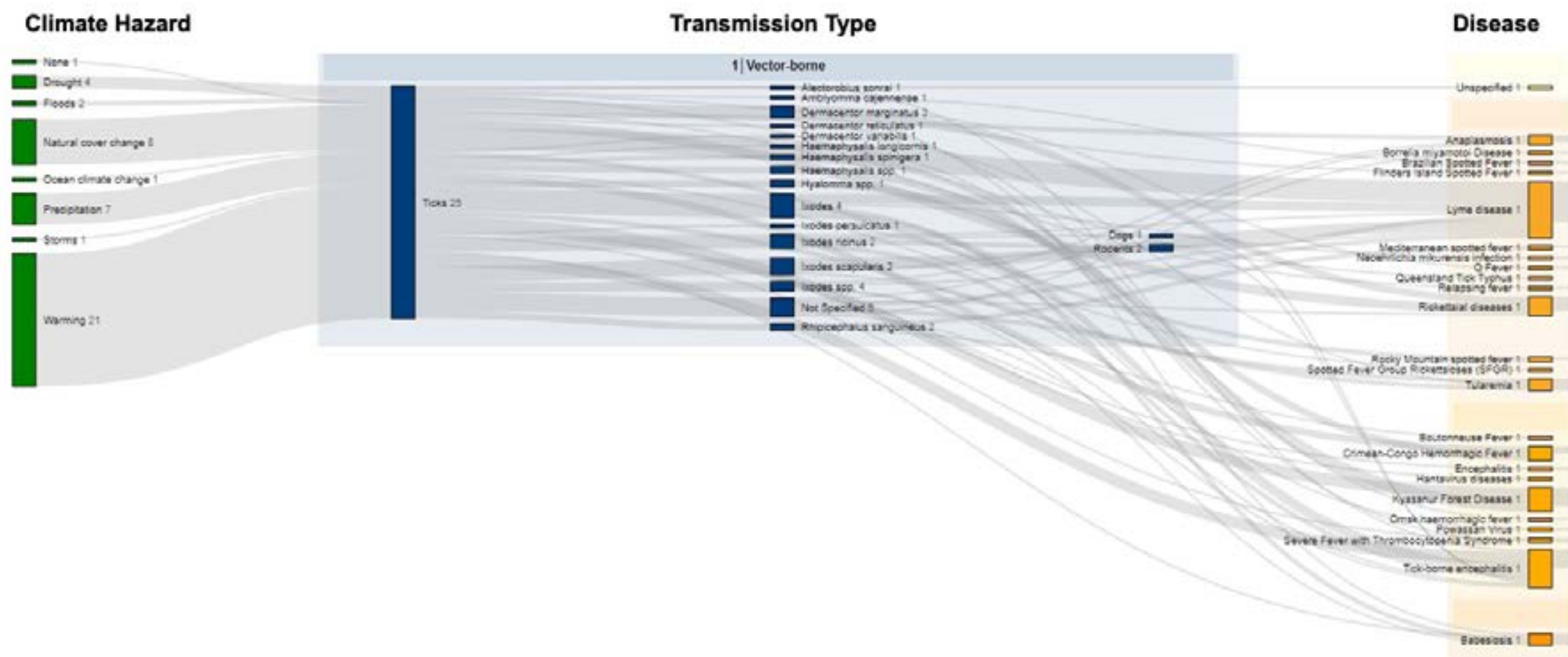
- In terms of climatic hazards, warming, precipitation, floods, drought and storms account for the majority, 555 out of 710, (78%) of published cases of pathogenic disease aggravation.
- Of the aggravated disease types, we see that VBDs represent the largest single group of published aggravated disease cases, followed by water-borne, air-borne, direct contact and food-borne, in all accounting for 347 out of 463 cases (75%).
- Viruses and bacteria account for by far the largest pathogen groups.

In the following sections, we will examine the current state of knowledge on specific VBDs, according to vector(s) and with reference to these effects in the European context. In most cases we have filtered the data to show only cases where disease aggravation (negative effects) has been found to occur due to climate change factors.

Short selected summaries of some of the relevant publications will then be presented in each section.

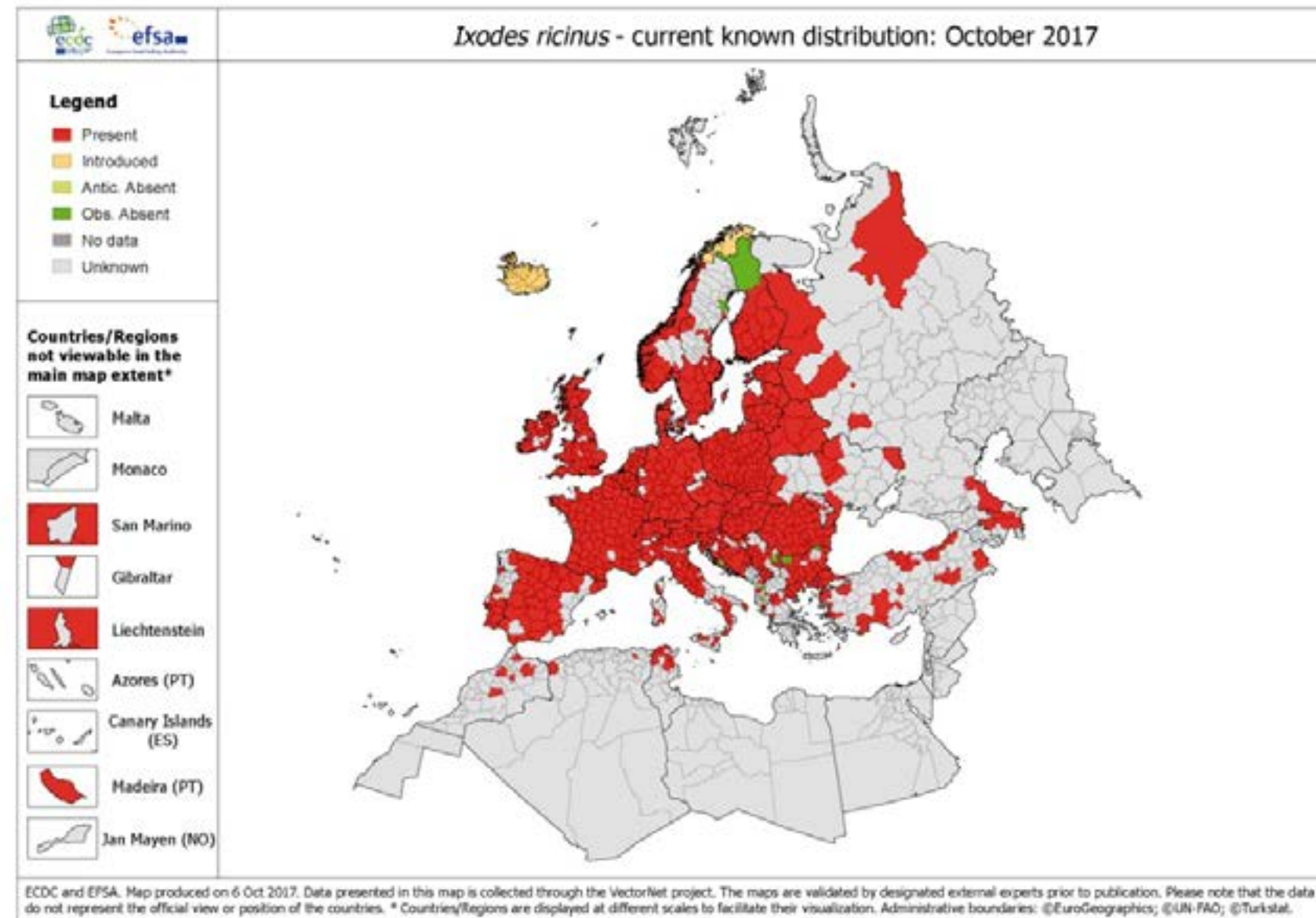
Note: Many of the publications on this topic refer to RCP climate change models. The Intergovernmental Panel on Climate Change (IPCC) has developed four Representative Concentration Pathway (RCP) scenarios for greenhouse gas emissions, ranging from a high-emission 'business-as-usual' scenario (RCP8.5), to a low-emission, aggressive mitigation scenario (RCP2.6).

5.2 Climate change effects according to vector: Ticks

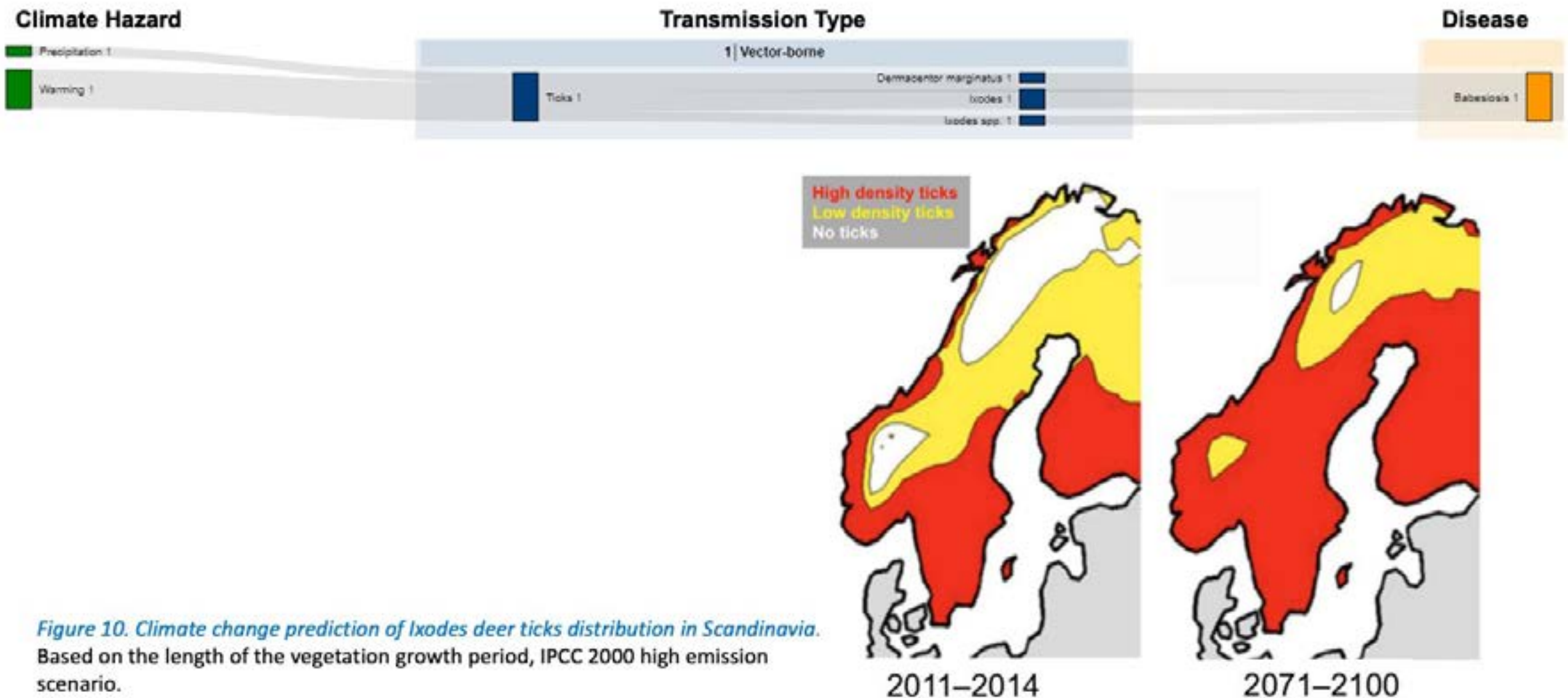


Here we can see that various species of ticks are responsible for 25 VBDs, and that these diseases are aggravated by 7 of the climate change effects discussed above, with global warming contributing to the majority (21) of these diseases.

Figure 9. Current European geographical distribution of ixodes ricinus ticks.



Looking at some of the specific tick-borne diseases: **Babesiosis**



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“Observations and models suggest that it is only a matter of time before human babesiosis cases occur more frequently, out of season and further north than at present as a result of climate change.”

From: : Gray, J.S.; Ogden, N.H., “Ticks, Human Babesiosis and Climate Change”. Pathogens, 2021, 10, 1430.

→ <https://doi.org/10.3390/pathogens10111430>

Crimean-Congo haemorrhagic fever (CCHF)

Climate Hazard

- Natural cover change 1
- Precipitation 1
- Warming 1

Transmission Type

1 | Vector-borne

Ticks 1

Hyalomma spp. 1

Disease

Crimean-Congo Hemorrhagic Fever 1

Country	Dates	% IgG
Portugal	1980	0.8 (2/258)
Spain	2010–2014	0 (0/228)
	2017	0 (0/49)
	2017–2018	0.58–1.16 (3/516–6/516) ¹
	2017–2018	3.0 (4/133) ²

Table 2. Seroprevalence of Crimean-Congo haemorrhagic fever virus (CCHFV) in humans in western Europe.

From: A. Portillo, A. M. Palomar, P. Santibáñez, and J. A. Oteo, "Epidemiological Aspects of Crimean-Congo Hemorrhagic Fever in Western Europe: What about the Future?", *Microorganisms*, 2021 Mar, **9**, (3), 649. <https://doi.org/10.3390%2Fmicroorganisms9030649>

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"...the demonstrated capacity of the virus for adaptation, among other factors, makes it a dangerous threat in our environment. CCHF, as other vector-borne viral diseases, is affected by dynamic factors such as globalization, climate change, social and cultural changes, alterations of land uses, habitats fragmentation, loss of

biodiversity, and introduction of exotic species.... All these facts, among others, combined with the different genotypes detected in ticks and humans in different areas from Spain suggest the potential establishment of a CCHFV transmission cycle. Therefore, a greater

awareness and surveillance of this threat is needed."

Lyme disease (Lyme borreliosis, LB)

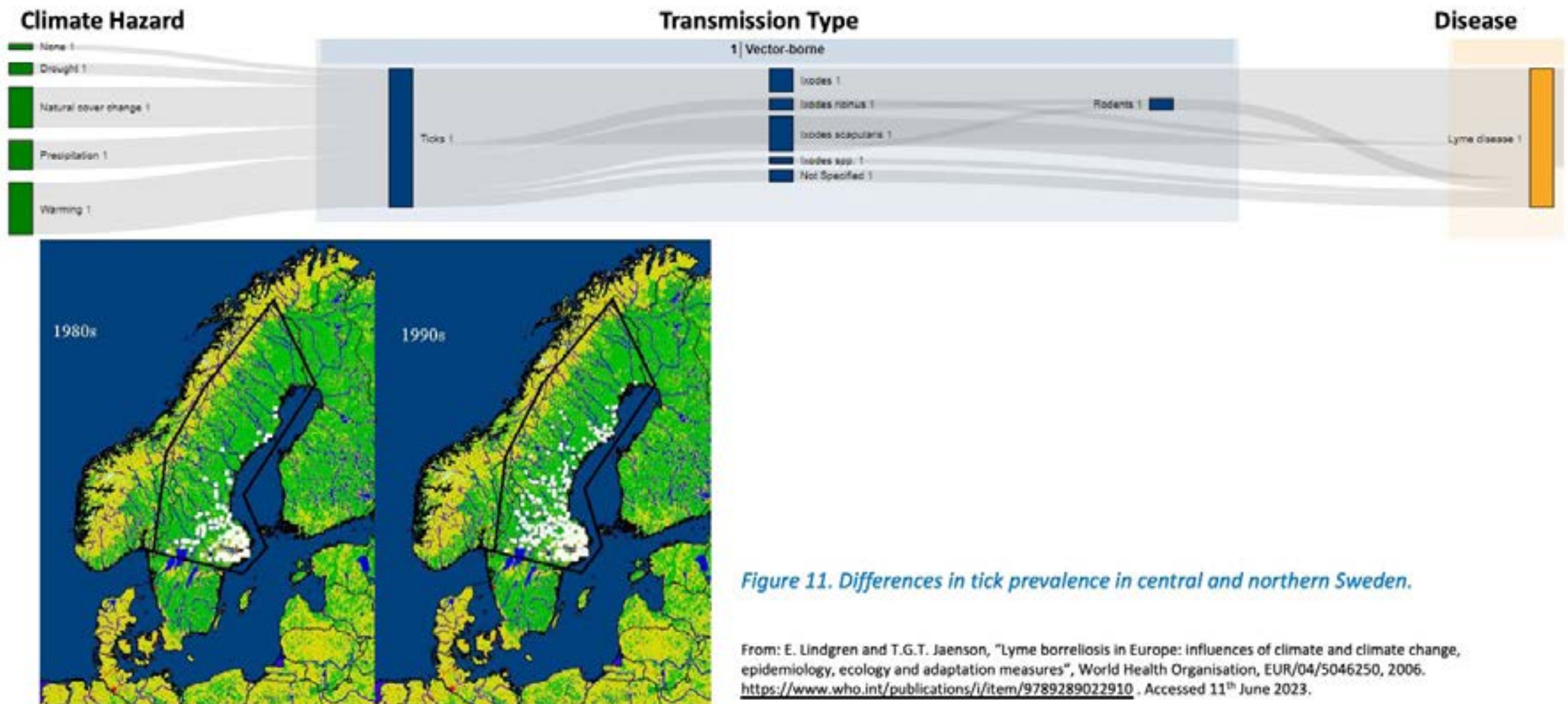


Figure 11. Differences in tick prevalence in central and northern Sweden.

From: E. Lindgren and T.G.T. Jaenson, "Lyme borreliosis in Europe: influences of climate and climate change, epidemiology, ecology and adaptation measures", World Health Organisation, EUR/04/5046250, 2006. <https://www.who.int/publications/i/item/9789289022910> . Accessed 11th June 2023.

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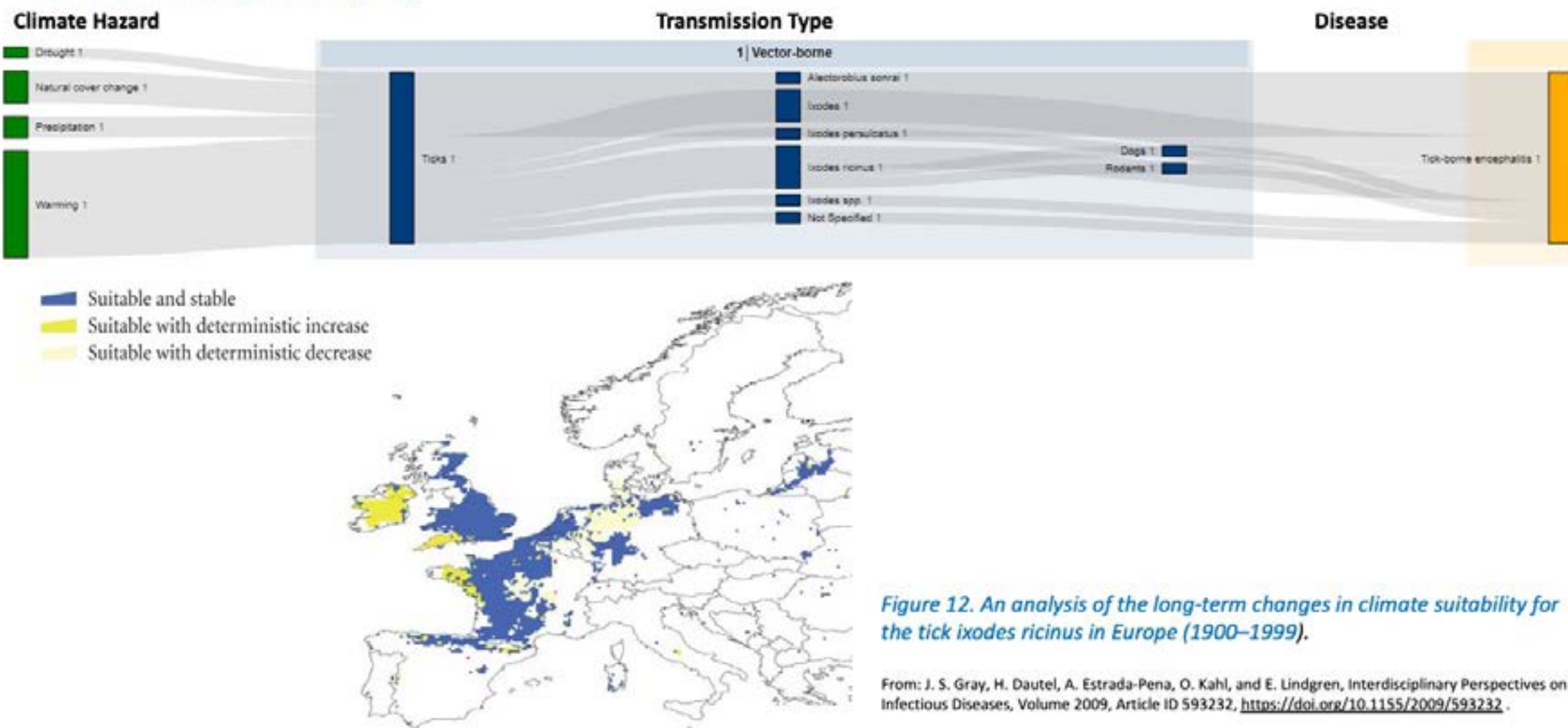
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Based on the results of all the different studies that have been reviewed it can be concluded that future climate change in Europe will facilitate a spread of LB into higher latitudes and altitudes, and contribute to an extended and more intense LB transmission season in some areas. In other areas, where future climate

change will cause climate conditions too hot and dry for tick survival, LB will disappear.

Tick-borne encephalitis (TBE)



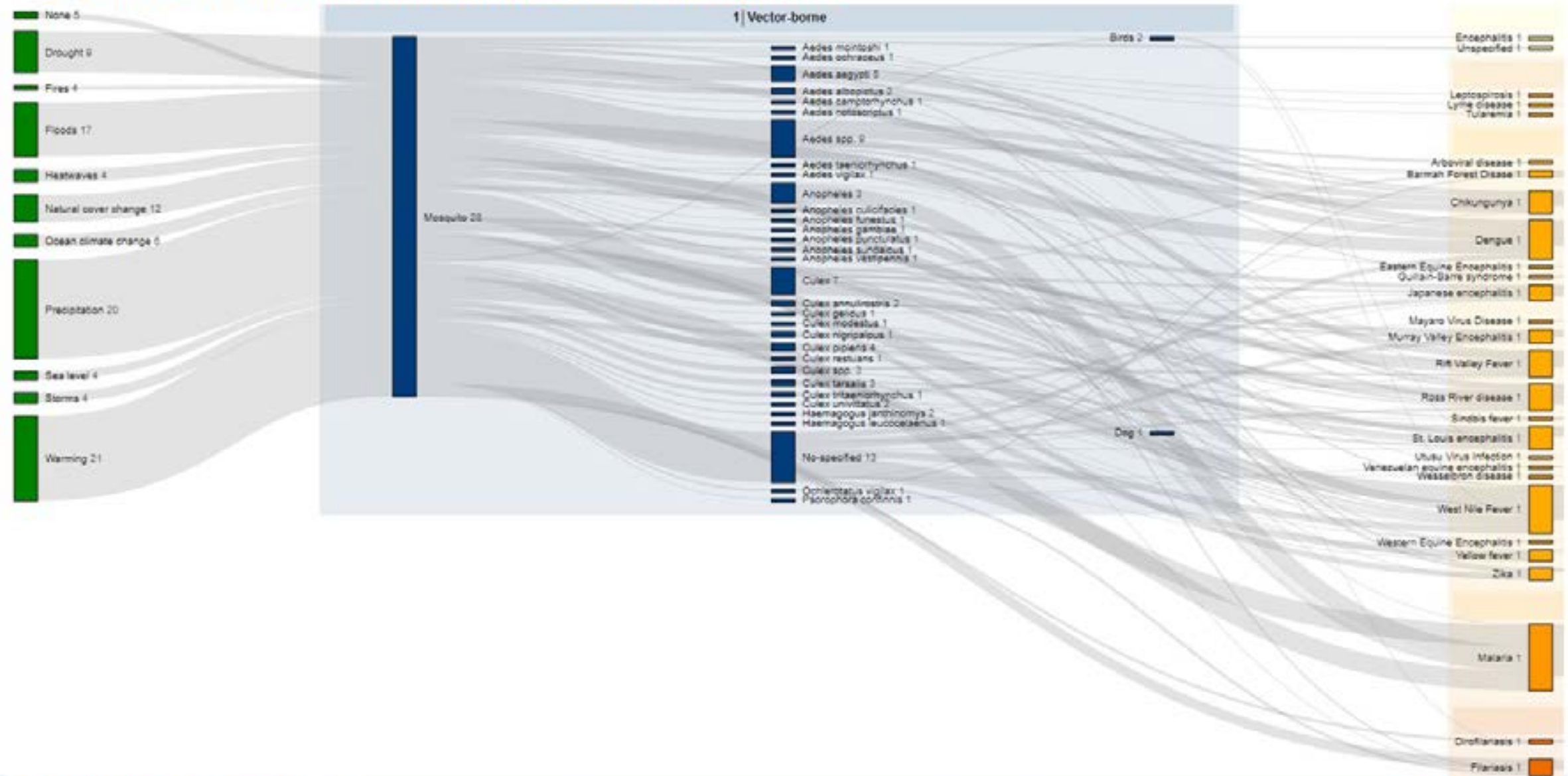
Areas are divided into suitable and unsuitable (the last, without colors in the figure). The area marked as suitable and stable means no changes in suitability for the tick. Deterministic increase or decrease means a continued trend towards increasing or decreasing climate suitability.

“Increases in Swedish cases since the mid-80s were associated with two consecutive years with milder winters, earlier arrival of spring and prolonged autumn periods with temperatures above

5-8°C. The possibility that this is caused by climate effects on ticks is suggested by the

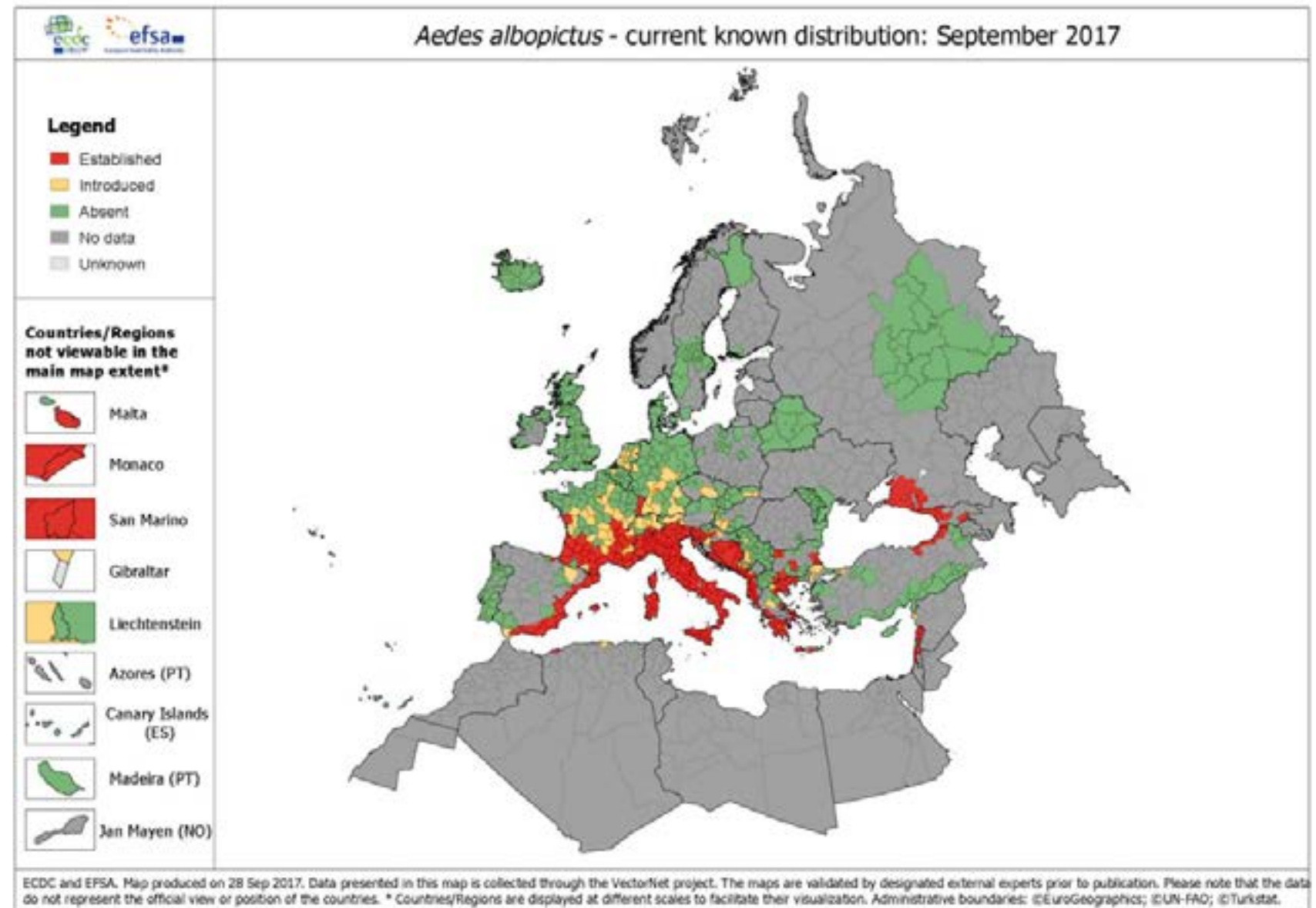
northward extension of *I. ricinus* distribution. Similarly, an upward movement of the TBE prevalence altitude ceiling correlating with increasing temperatures has been reported, which accords with reports of increasing numbers of active ticks at higher altitudes...”

5.3 Climate change effects according to vector: Mosquitoes



Here we can see that various species of mosquitoes are responsible for 28 VBDs, and that these diseases are aggravated by all 10 of the climate change effects discussed above, with global warming, precipitation, and flooding contributing to the majority (21) of these diseases.

Figure 13. Current European geographical distribution of *aedes albopictus* mosquitoes.



Looking at some of the specific mosquito-borne diseases: **Chikungunya (CHIKV)**

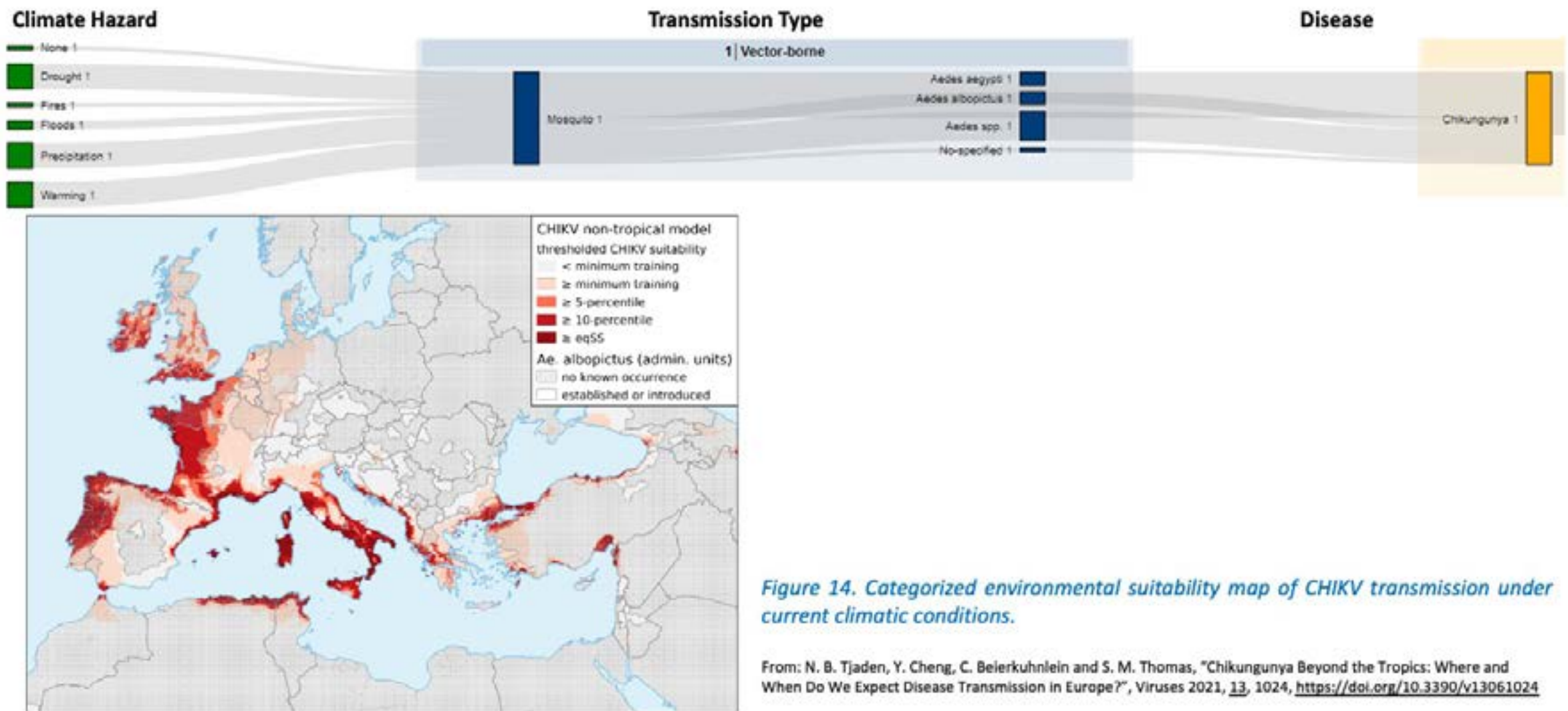


Figure 14. Categorized environmental suitability map of CHIKV transmission under current climatic conditions.

From: N. B. Tjaden, Y. Cheng, C. Belerkuhnlein and S. M. Thomas, "Chikungunya Beyond the Tropics: Where and When Do We Expect Disease Transmission in Europe?", *Viruses* 2021, **13**, 1024, <https://doi.org/10.3390/v13061024>

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Based on an ecological niche model of 160 global chikungunya case localities outside the tropics.

"...we applied an epidemiological model to capture the temporal outbreak risk of chikungunya in six selected European cities.... Highly suitable areas are more widespread than

previously assumed. They are found in coastal areas of the Mediterranean Sea, in the western part of the Iberian Peninsula, and in Atlantic coastal areas of France. Under a worst-case scenario, even large areas of western Germany and the Benelux states are considered potential areas of transmission."

Dengue fever

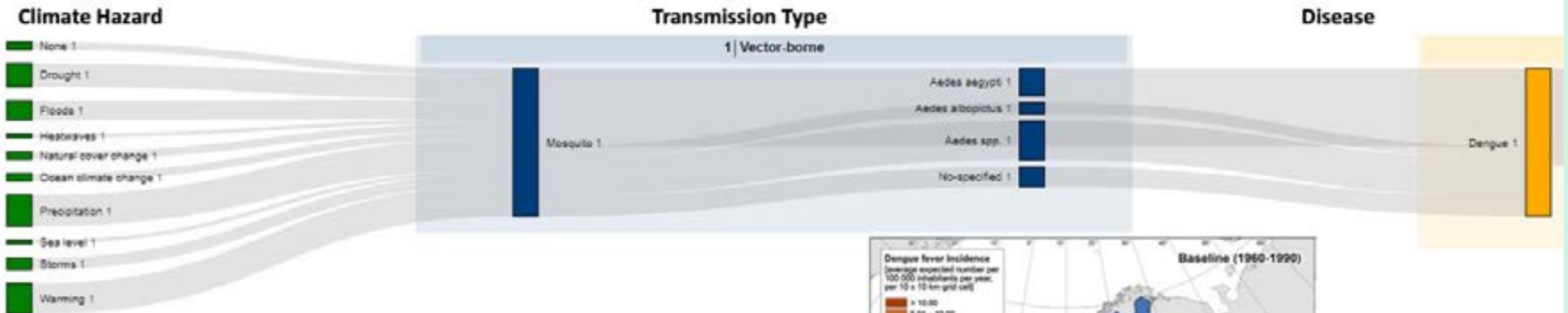
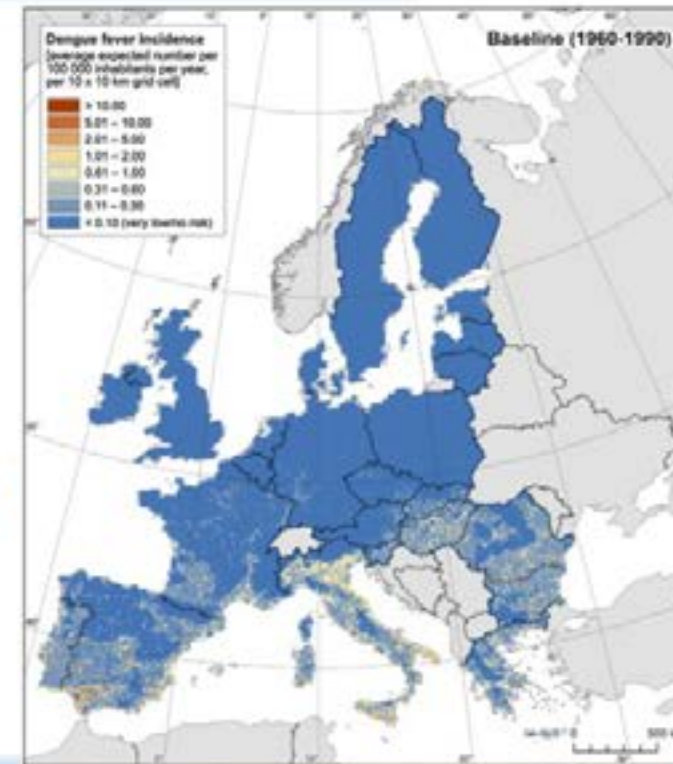


Figure 15. Dengue fever incidence rate expressed as number of cases per 100,000 inhabitants per year for baseline conditions and climate change scenarios.



From: M. Bouzid, F. J. Colón-González, T. Lung, I. R. Lake, and P. R. Hunter, BMC Public Health, 2014, **14**, 781. <http://www.biomedcentral.com/1471-2458/14/781>. Accessed 11th June 2023.

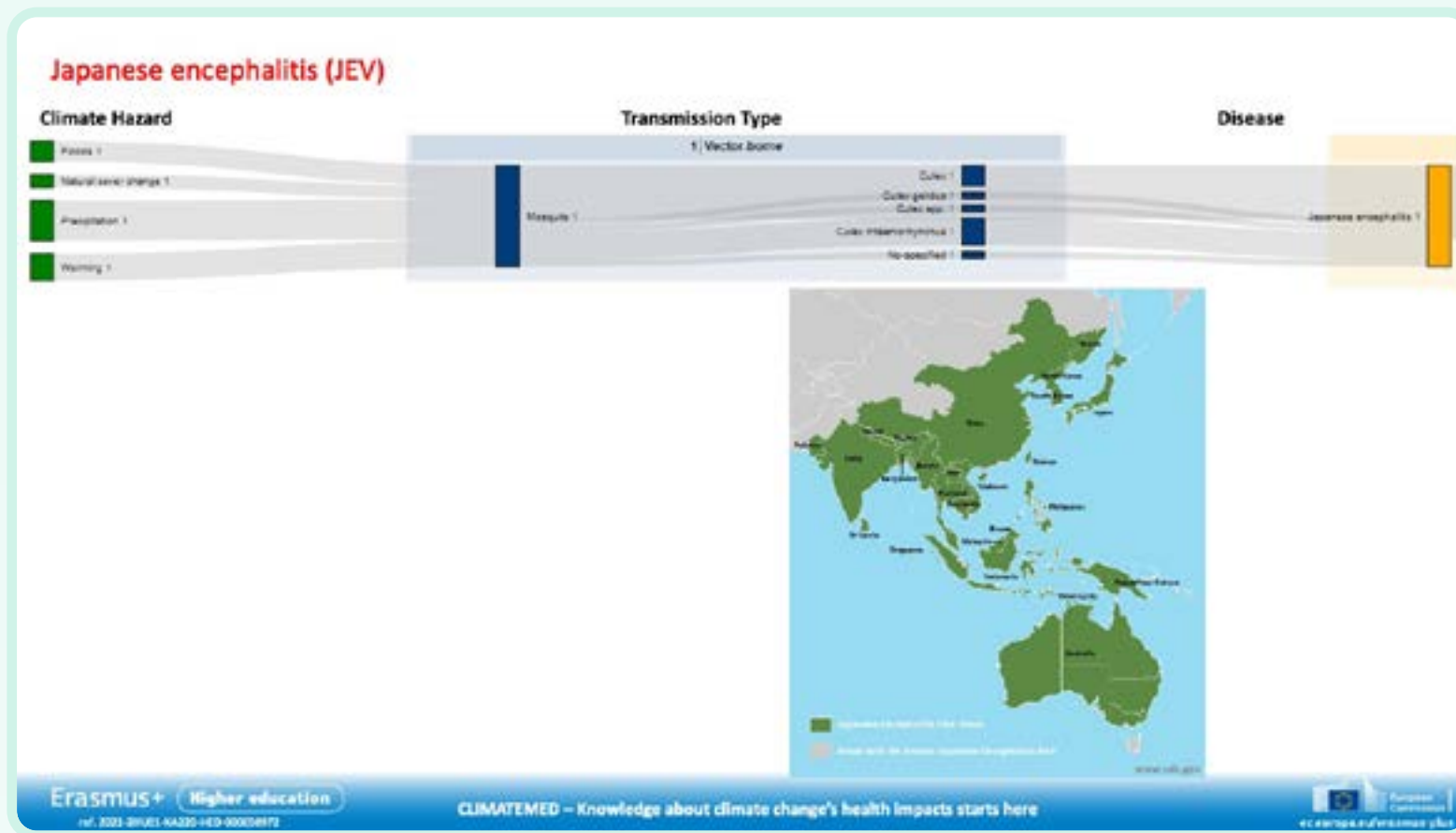
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“The risk maps indicate that climate change is likely to contribute to increased dengue risk (and possibly other mosquito-borne diseases) in many parts of Europe, especially towards the end of the century. The areas of greatest increased risk are projected to be clustered

around the Mediterranean and Adriatic coasts and in northern Italy.”



"....with changing climate JEV has the potential to emerge in novel temperate regions. Here, we have assessed the vector competence of the temperate mosquito *Culex pipiens* f. *pipiens* to vector JEV genotype III at temperatures representative of those experienced, or predicted in the future during the summer months, in the United Kingdom. Our results show that *Cx. pipiens* is susceptible to JEV infection at both temperatures."

From: A. J. Folly, D. Dorey Robinson, L. M. Hernández Triana, S. Ackroyd, B. Vidana, F. Z. X. Lean, D. Hicks, A. Nuñez and N. Johnson, "Temperate conditions restrict

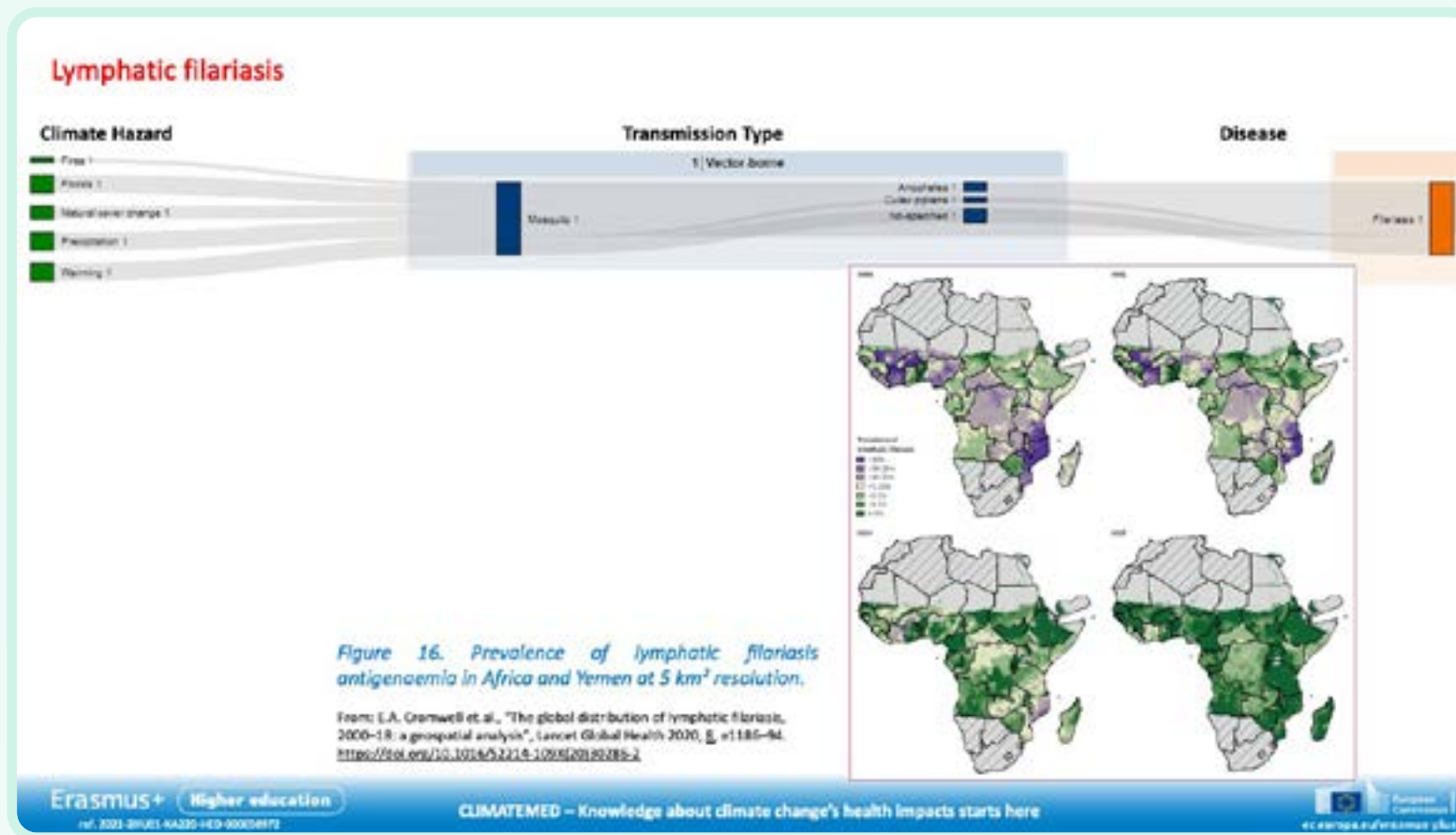
Japanese encephalitis virus infection to the mid gut and prevents systemic dissemination in *Culex pipiens* mosquitoes", *Nature Scientific Reports*, 2021, 11, 6133.

"There is a possible risk of introduction of Japanese encephalitis virus in European Union/European Economic Area countries via international travel and commerce with Asia and Oceania, which could facilitate the introduction of mosquitoes infected with the virus. If the virus is introduced, it could become established in Europe due to the significant number of susceptible mosquito vectors and vertebrate hosts. The identification of a Japanese encephalitis viral RNA fragment in one *Culex* mosquito pool in northern Italy in 2010 might demonstrate a wider range of distribution of the virus and a potential public health threat in Europe."

From: European Centre for Disease Prevention and Control, "Factsheet about Japanese encephalitis".

→ <https://www.ecdc.europa.eu/en/japanese-encephalitis/facts>

→ <https://doi.org/10.1038/s41598-021-85411-2>



Although the prevalence of lymphatic filariasis infection has declined since 2000, mass drug administration is still necessary across large populations in Africa and Asia.

Transmission areas in Africa are predicted to expand, with northern and southern extremes of the continent becoming endemic in the future. With both climate change and population growth considered, the at-risk population in Africa, currently estimated to be 543–804 million, could rise to a possible 1.65–1.86 billion in future scenarios. However, these predictions do not take into account accelerating global control activities.

From: R. Tidman, B. Abela-Ridder, and R. Ruiz de Castañeda, The impact of climate change

on neglected tropical diseases: a systematic review", *Trans R Soc Trop Med Hyg* 2021, 115, 147–168

→ <https://doi.org/10.1093/trstmh/traa192>

Malaria

Climate Hazard

- None 1
- Drought 1
- Fires 1
- Floods 1
- Heatwaves 1
- Natural cover change 1
- Ocean climate change 1
- Precipitation 1
- Sea level 1
- Storms 1
- Warming 1

Transmission Type

1 | Vector-borne

Mosquito 1

Aedes spp. 1

Anopheles 1

Anopheles culicifacies 1

Anopheles funestus 1

Anopheles gambiae 1

Anopheles punctulatus 1

Anopheles sundicus 1

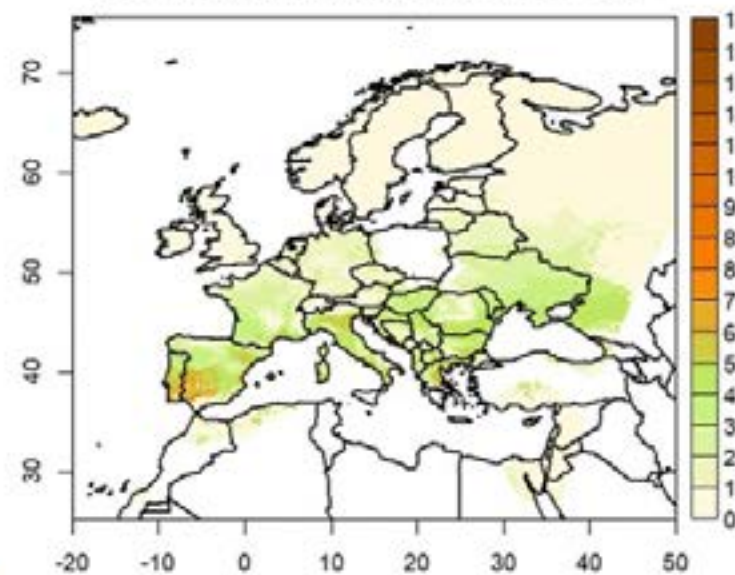
Anopheles vestipennis 1

No-specified 1

Disease

Malaria 1

Vector Stability Index Historical 1985-2005



Vector Stability Index RCP8.5 2080-2100

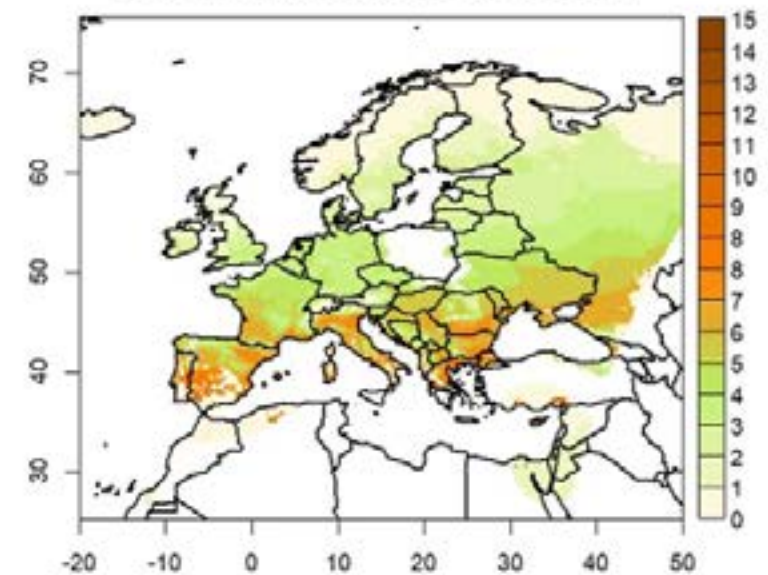


Figure 17. Malaria vector stability: historical and predicted from regional climate models (RCMs).

Vector Stability Index. Shown are the values for the historical period 1985–2005 (a) and for the scenario period 2080–2100 under the RCP8.5 scenario (b). White areas denote regions with no observational and/or RCM data

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Countries affected by an increased malaria risk comprised for instance Spain, southern France, Italy, Greece, the eastern European countries Bulgaria, Romania, Macedonia and Serbia as well as southern Ukraine and Russia.

stability in Europe and the Mediterranean area under future climate change, Parasites & Vectors, 2019, 12, 18.

→ <https://doi.org/10.1186/s13071-018-3278-6>

From: E. Hertig, Distribution of Anopheles vectors and potential malaria transmission

Rift valley fever (RVF)

Climate Hazard

- None 1
- Drought 1
- Floods 1
- Natural cover change 1
- Ocean climate change 1
- Precipitation 1
- Warming 1

Transmission Type

1 | Vector-borne

Mosquito 1

- Aedes mcintoshi 1
- Aedes ochraceus 1
- Aedes aegypti 1
- Aedes spp. 1
- Culex 1
- Culex spp. 1
- Not specified 1

Disease

Rift Valley Fever 1

Table 3. Competent mosquito vectors of Rift Valley fever virus with known distribution in the European Union.
(X = vector present; ? = unknown to the authors, or not found yet).

Country	Aedes vexans vexans	Ochlerotatus caspius	Culex theileri	Culex pipiens	Culex perexiguus
Austria	X	X	?	X	?
Belgium	X	X	?	X	?
Bulgaria	X	X	X	X	X
Croatia ¹	X	X	?	X	?
Cyprus	?	X	?	X	?
Czech Republic	X	X	?	X	?
Denmark	X	X	?	X	?
Estonia	X	X	?	X	?
Finland	X	X	?	X	?
France (mainland)	X	X	X	X	?
France (Corsica)	X	X	X	X	?
Germany	X	X	?	X	?
Greece	X	X	X	X	X
Hungary	X	X	X	X	?
Ireland	?	X	?	X	?
Italy (mainland)	X	X	X	X	X

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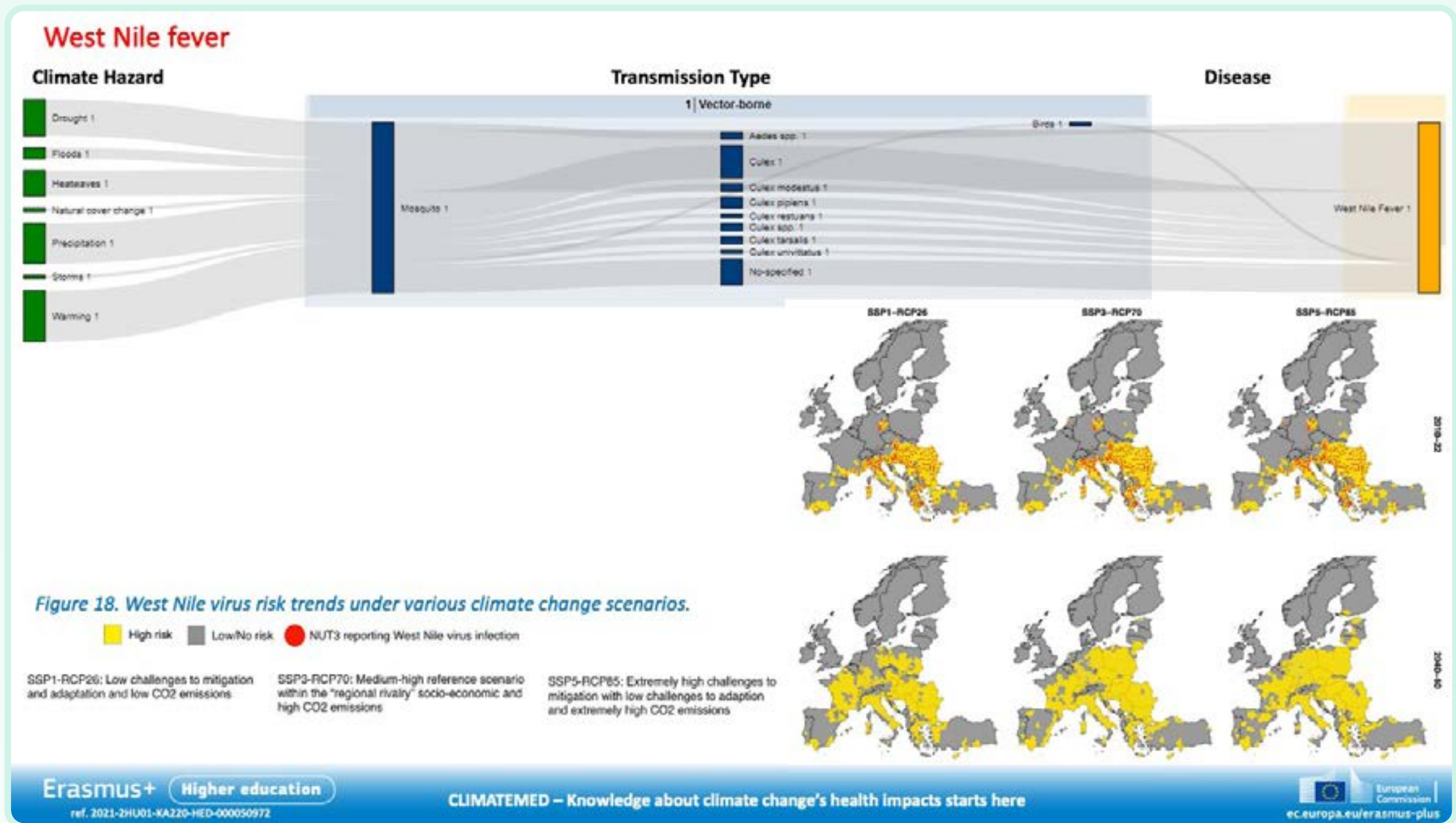
...analyses have been conducted to assess the risk of the introduction and spread of RVF within the EU. The conclusions have been that the overall risk was low. However, the recent reappearance of RVF in East Africa, including Sudan, the Nile Valley, and the Indian Ocean, has shown that the RVFV is very active and

sensitive to climate and other environmental as well as socio-economic changes...Consequently, the Mediterranean basin, central Europe, and the Middle East will probably be increasingly exposed to the risk of introduction of RVF.

From: : V. Chevalier, M. Pépin, L. Plée, and R. Lancelot. "Rift Valley fever - a threat for Europe?". Euro Surveill. 2010, 15 , (10), pii=19506.

→ <https://www.eurosurveillance.org/content/10.2807/ese.15.10.19506-en>

↘ Accessed 11th June 2023.



WNV, already endemic in parts of European countries, will likely continue to disperse to naive areas, as conditions for its vectors become more favourable due to the changing climate. Western Europe could be facing large outbreaks of the virus, irrespective of the future degree of climate change, calling for the need to adapt

to this new situation. Under high emission scenarios, WNV could even expand to Northern Europe later in this century.

From: Z. Farooq et al., One Health 2023, 16, 100509.

→ <https://doi.org/10.1016/j.onehlt.2023.100509>

Yellow fever

Climate Hazard

- Drought 1
- Fires 1
- Floods 1
- Natural cover change 1
- Precipitation 1
- Warming 1

Transmission Type

1 | Vector-borne

Mosquito 1

- Aedes spp. 1
- Haemagogus janthinomys 1
- Haemagogus leucocelaenus 1
- No-specified 1

Disease

Yellow fever 1

Figure 19. Expansion of invasion frontiers of *Aedes aegypti* in Europe from 1950–2050 under the RCP 8.5 (high CO₂ emissions) climate change model.

“Europe is expected to experience isolated areas of sustained suitability for *Ae. aegypti* in Spain, Portugal, Greece and Turkey by 2030.”

From: T. Iwamura, A. Guzman-Holst and K. A. Murray, Nature Communications (2020) 11, 2130. <https://doi.org/10.1038/s41467-020-16010-4>

“In 2030 the climatic conditions in southern Spain will be favorable to the establishment of the yellow fever mosquito.”

From: <http://www.mosquitoalert.com/en/el-cambio-climatico-acelera-la-expansion-del-mosquito-de-la-fiebre-amarilla/>. Accessed 11th June 2023.

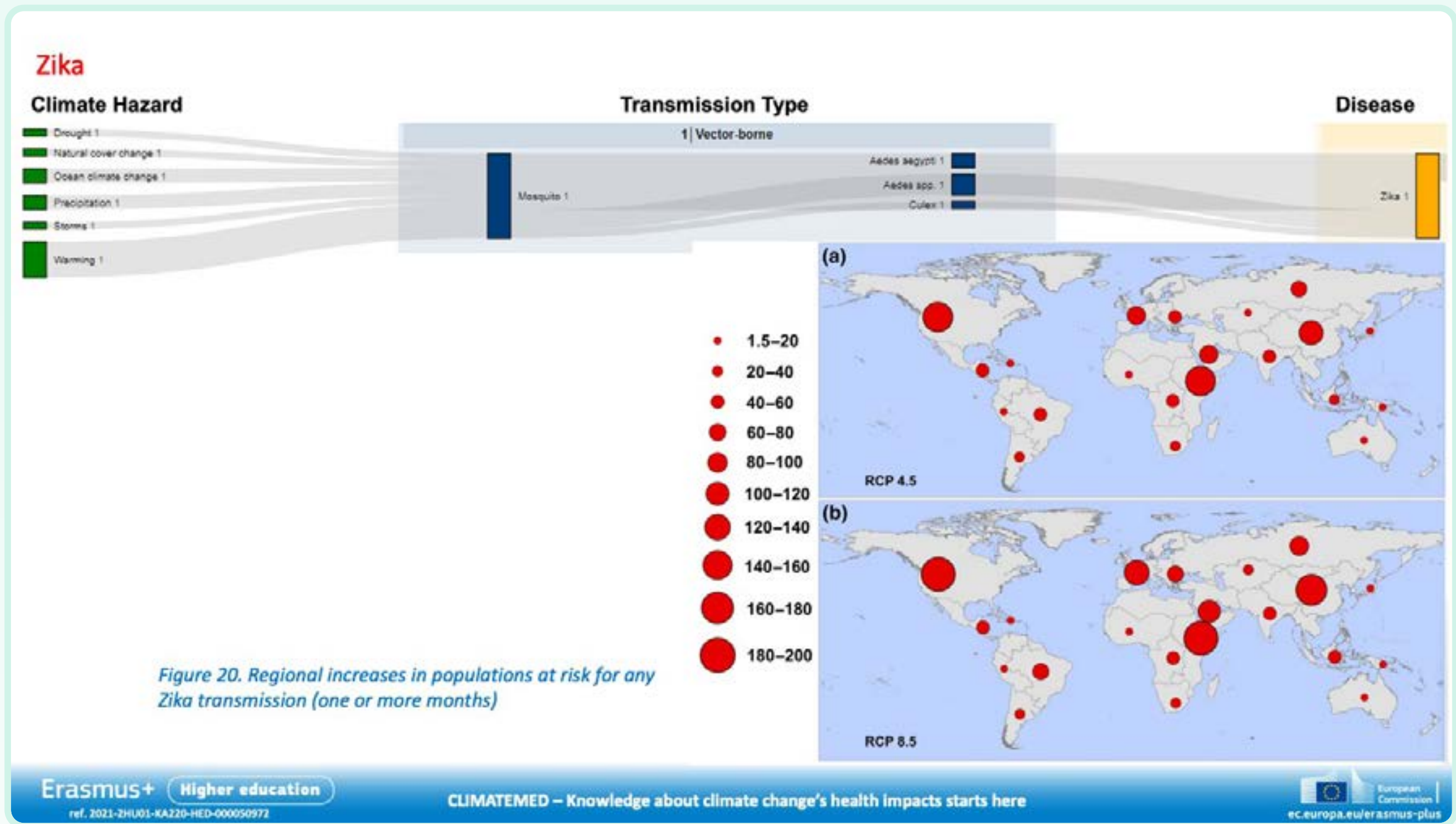


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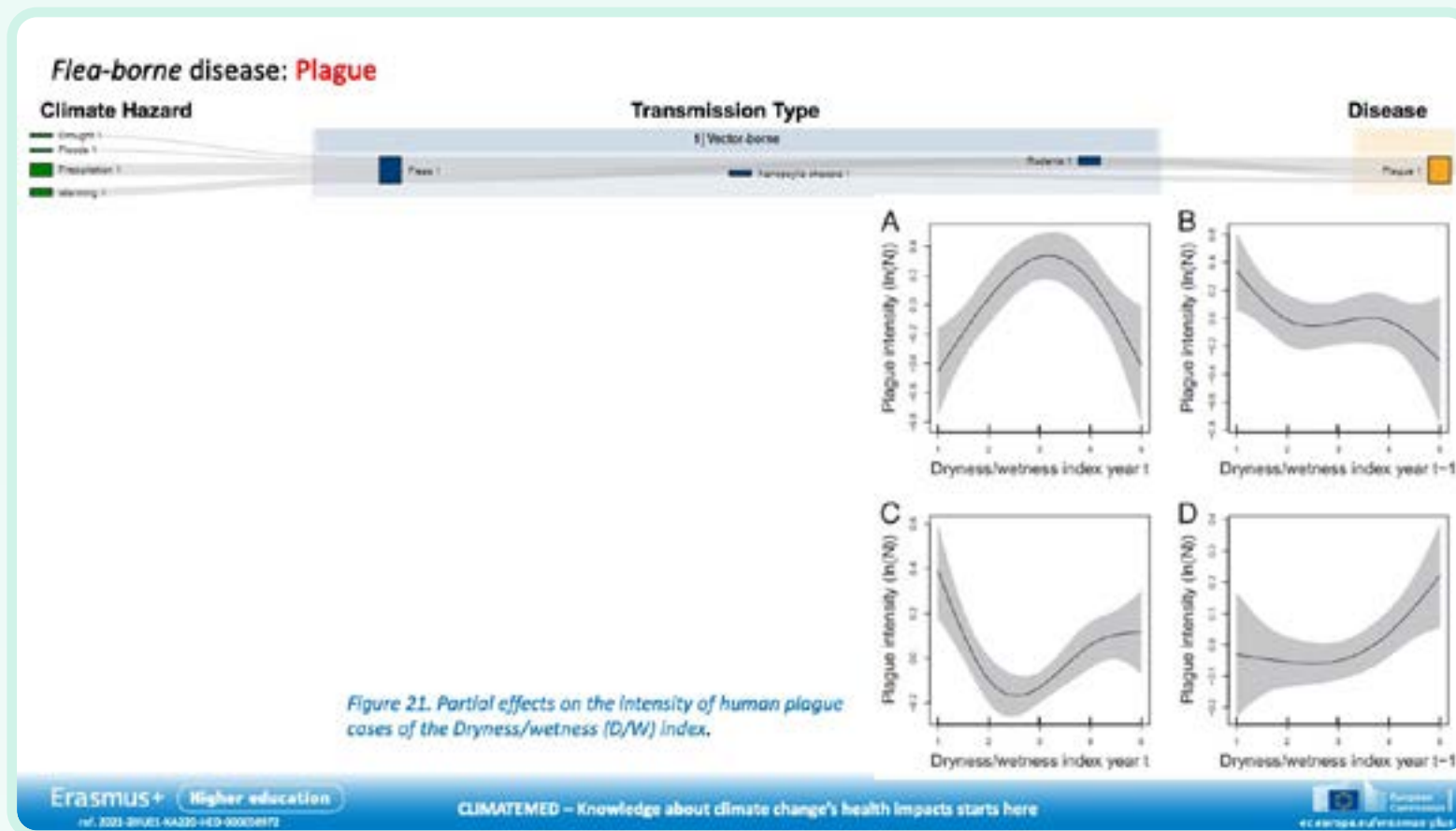
Proportional red circles illustrate the regional populations (in millions) at risk under (a) moderate (RCP 4.5) and (b) extreme (RCP 8.5) climate change models.

Based on these model predictions, in the worst-case scenario, over 1.3 billion new people could face suitable transmission temperatures

for ZIKV by 2050. The next generation will face substantially increased ZIKV transmission temperature suitability in North America and Europe, where naïve populations might be particularly vulnerable.

From: S. J. Ryan, C. J. Carlson, B. Tesla, M. H. Bonds, C. N. Ngonghala, E. A. Mordecai, L. R. Johnson, C. C. Murdock, *Global Change Biology*, 2021, 27, 84–93.

→ | <https://doi.org/10.1111/gcb.15384>



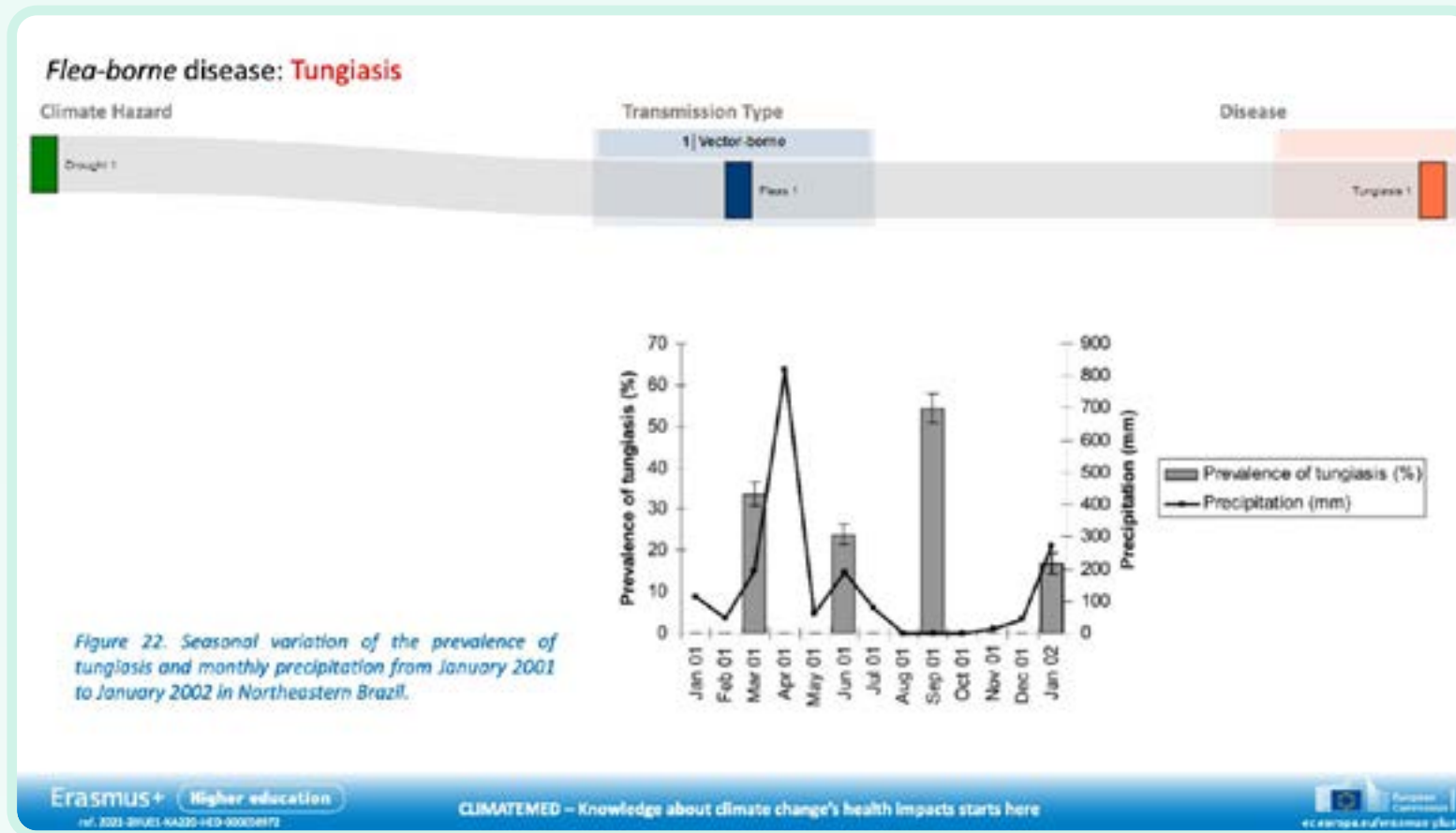
In the current year (A) and previous year (B) in northern China, and of the D/W index in the current year (C) and previous year (D) in southern China. D/W: 1 = very wet; 5 = very dry.

Our results demonstrate that the response of human plague to dryness/wetness index was nonlinear at a regional scale. In general, drier conditions were associated with decreased plague intensity in northern China and with increased plague intensity in southern China. Extreme wetness had, however, opposite short term effects, leading to a dome-shaped effect of the current-year dryness/wetness index in the north and a U-shaped effect in the south. The contrasting effects found for northern and southern China suggest that the effects of

precipitation on human plague intensity may differ between climatic zones.

From: L. Xua et al., "Nonlinear effect of climate on plague during the third pandemic in China", PNAS, June 21, 2011, 108, (25), 10214–10219.

→ <https://www.pnas.org/doi/full/10.1073/pnas.1019486108>



From: J. Heukelbach, T. Wilcke, G. Harms and H. Feldmeier, "Seasonal Variation of Tungiasis in an Endemic Community", Am. J. Trop. Med. Hyg., 2005, 72, (2), 145–149.

→ https://camilo-mora.github.io/Diseases/PDFs/Seasonal_variation_of_Tungiasis_in_an_endemic_comm.pdf

Tourism in endemic regions and globalization may result in new cases in developed countries and previously unaffected regions, therefore pathologists should consider this parasitic disease (Tungiasis).

From: A. Palicelli et al., "Tungiasis in Italy: An imported case of *Tunga penetrans* and review of the literature." Pathology – Research and Practice, 2016, 212, 475–483.

→ <http://dx.doi.org/10.1016/j.prp.2016.02.003>

Our data show that the prevalence of tungiasis was significantly higher in the dry than in the rainy season...Seasonal variation of attack rates and incidence probably is caused by biological dynamics of the sand flea population, reflecting changes of environmental variables. During the rainy season, high soil humidity may impair the development of free-living stages of sand fleas, and heavy precipitations will wash away eggs, larvae, pupae, and adult stages from the area where they developed.

Flea-borne disease: Typhus

Climate Hazard



Transmission Type

1 | Vector-borne

Phase 1

Disease

1 | Bacteria

Typhus 1

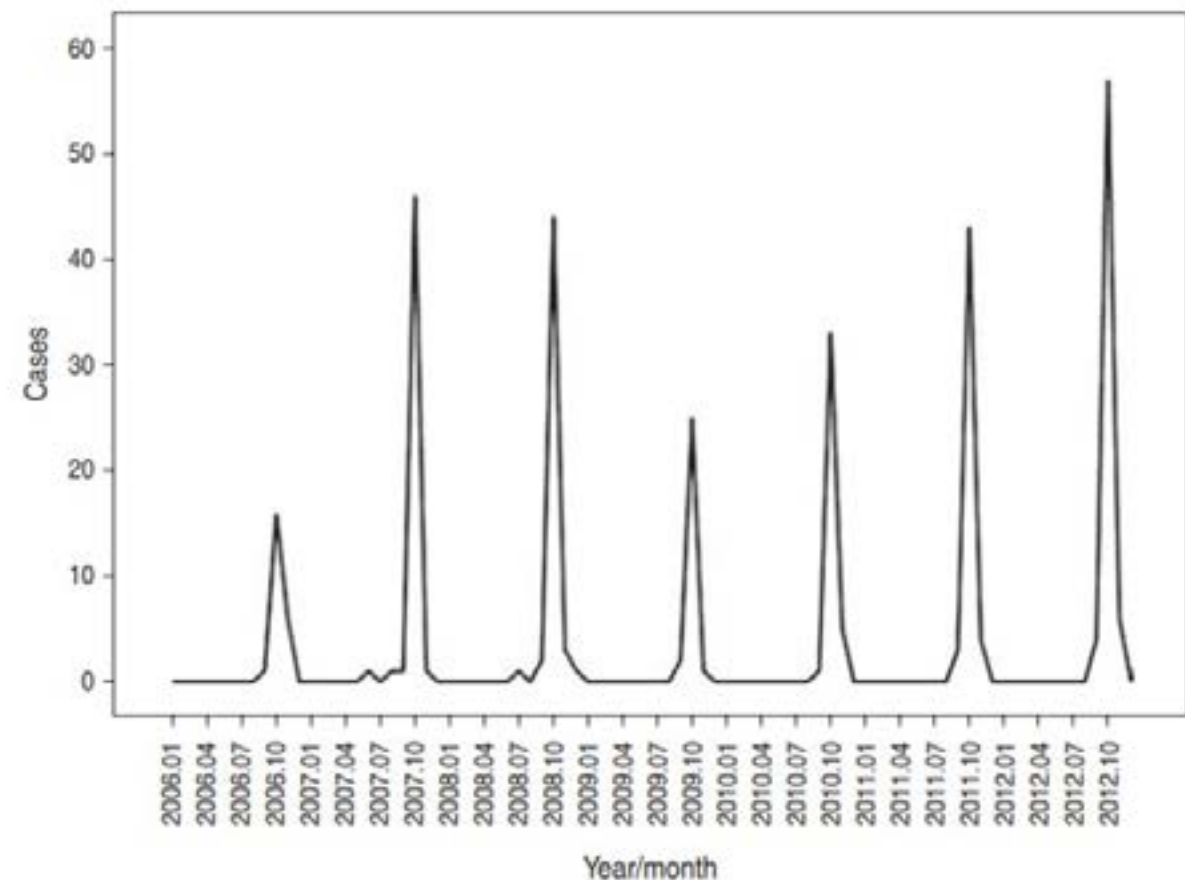


Figure 23. Scrub typhus cases in Laiwu, China from 2006 to 2012

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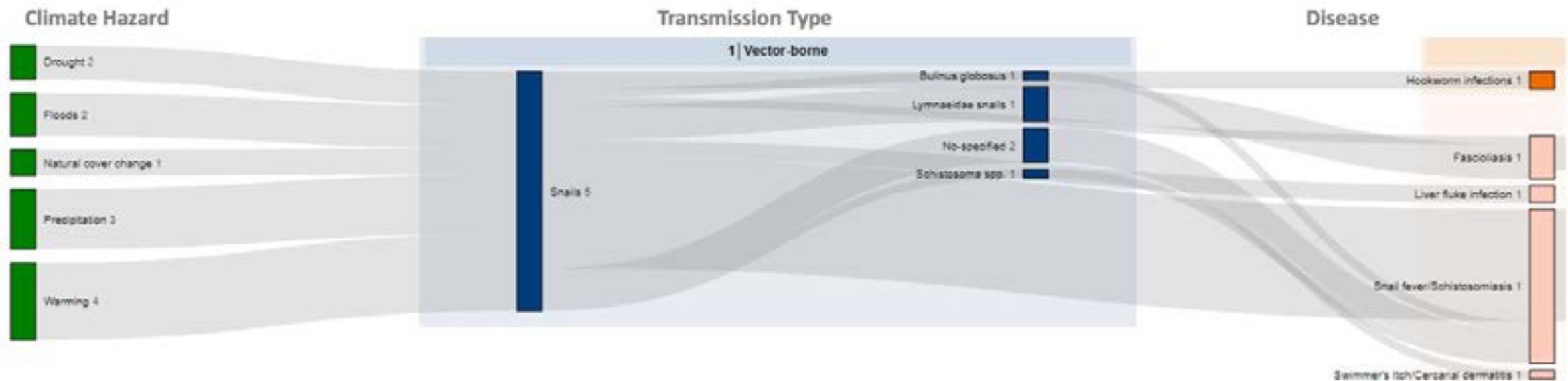
“.....the occurrence of scrub typhus is positively correlated with temperature in the previous 3 months, humidity in the previous 2 months and precipitation in the previous 3 months in Laiwu, China. Climate change, particularly global warming, coupled with the positive correlation between temperature and scrub typhus may

increase the prevalence of scrub typhus in temperate regions.”

L. P. Yang, J. Liu, X. J. Wang, W. MA, C. X. Jia, and B. F. Jiang, “Effects of meteorological factors on scrub typhus in a temperate region of China”, *Epidemiol. Infect.*, 2014, 142, 2217–2226.

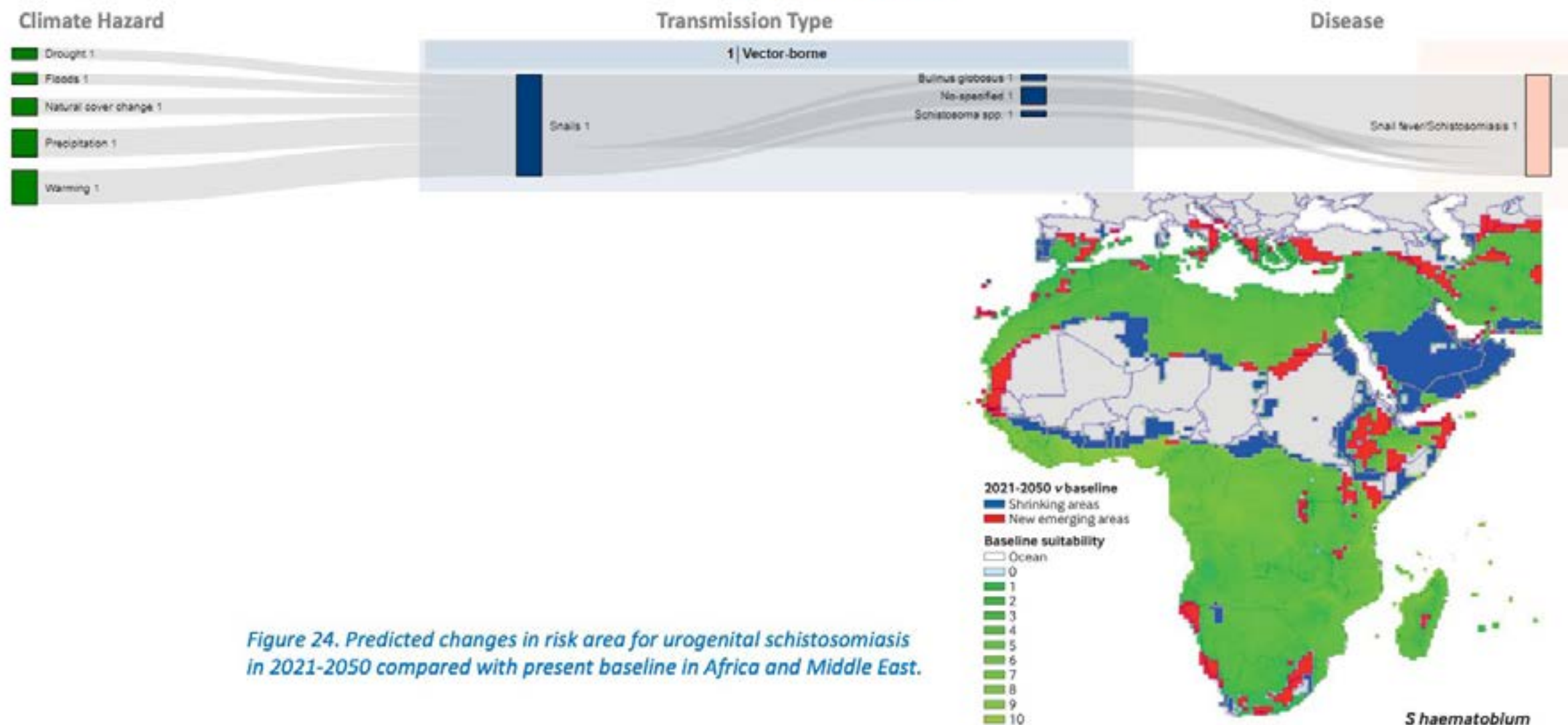
→ | <https://doi.org/10.1017/S0950268813003208>

5.5 Climate change effects according to vector: **Snails**



Here we can see that various species of snails are responsible for 5 VBDs, and that these diseases are aggravated by 5 of the climate change effects discussed above, with global warming and precipitation responsible for 4 of the diseases.

Looking at some of the specific snail-borne diseases: **Schistosomiasis**



Suitability ranges from zero (not suitable conditions) to 10 (most suitable). Blue colour indicates shrinking areas for schistosomiasis as the temperature becomes unsuitable for the parasite to persist.

A similar modelling approach was used to map the predicted change in risk of *S. haematobium* for 2021-2050. The model highlighted potential emerging, as well as contracting, areas in Africa, the Middle East, and southern parts of Europe.

From: G. A. De Leo et al., BMJ 2020, 371, m4324.

→ <http://dx.doi.org/10.1136/bmj.m4324>

Hookworm infection

Climate Hazard

Transmission Type

Disease



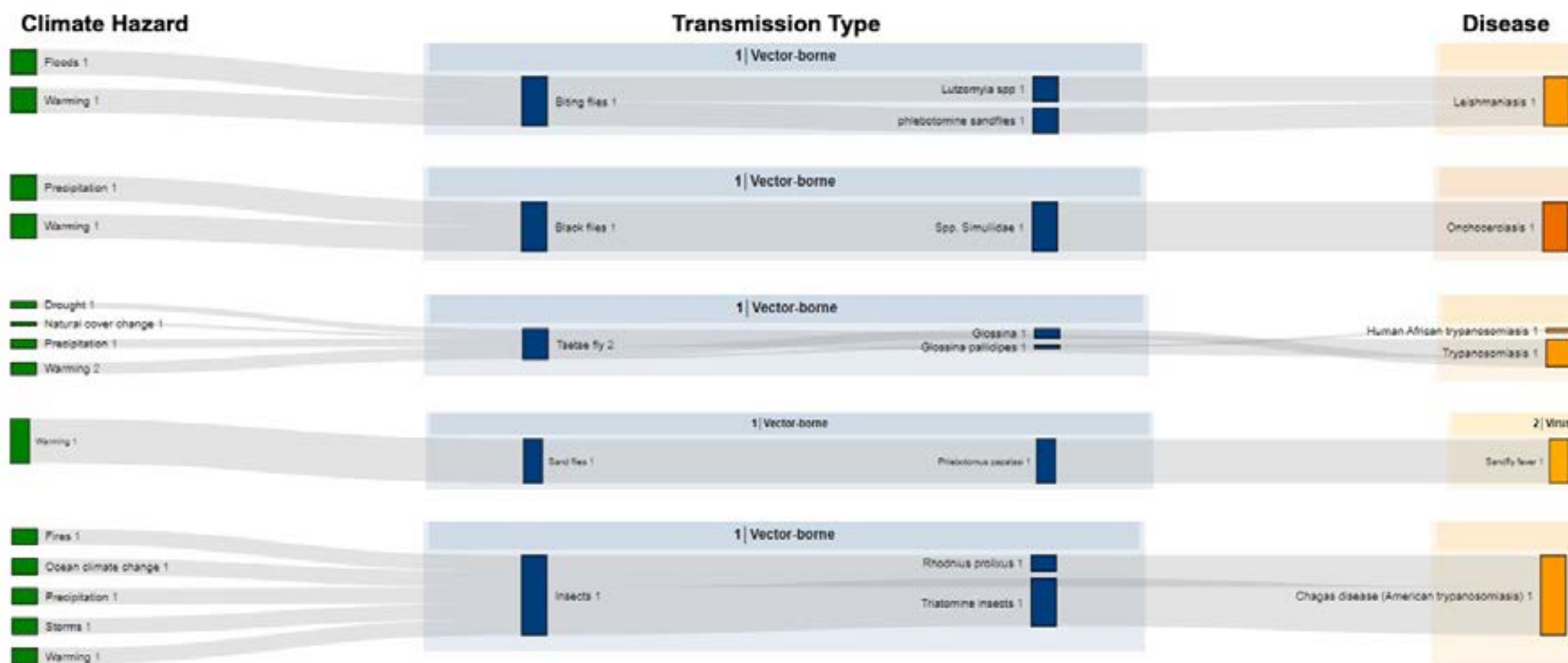
Climatic variable	Effect on STHs
Increased temperature	<p>Hookworm:</p> <ul style="list-style-type: none"> Increased rate of L₁ and L₂ development, reducing time taken to infectivity. Increased metabolic rate of L₃, negatively affecting survival. Temperatures exceeding maximum for development will cause reduced transmission. <p><i>A. lumbricoides</i> and <i>T. trichiura</i>:</p> <ul style="list-style-type: none"> Increase development within egg; decrease time to infectivity. Decreased egg viability above certain temperatures.
Increased precipitation	<p>All:</p> <ul style="list-style-type: none"> Prevention of egg/larval desiccation, but only to a degree, excessively high rainfall could reduce egg hatching/larval development.
Decreased precipitation	<p>All:</p> <ul style="list-style-type: none"> Reduced egg hatching/larval development.
Increased relative humidity	<p>All:</p> <ul style="list-style-type: none"> Prevent desiccation, increase survival rates. <p>Hookworm:</p> <ul style="list-style-type: none"> Facilitate increased larval survival in soil.
Decreased relative humidity	<p>All:</p> <ul style="list-style-type: none"> Facilitate increased larval survival in soil. <p>Hookworm:</p> <ul style="list-style-type: none"> Reduced larval survival in soil.

“Complex sets of biological, behavioural and socioeconomic factors interact and play a large part in the actual or realized distribution of STHs... STH infections might not be an exclusively tropical concern. Recent climate-related events suggest the potential for disease emergence in industrialized regions of the world. For example, emergence of infections and cutaneous larva migrans in Berlin, Germany, of *Ancylostoma caninum*, a zoonotic hookworm... were associated with periods of extreme and prolonged elevated temperatures and high humidity. This raises the question about modified patterns of larval survival and abundance resulting from the changing climate, and the possibility of extended distributions of infection and/or disease in boreal and temperate latitudes.”

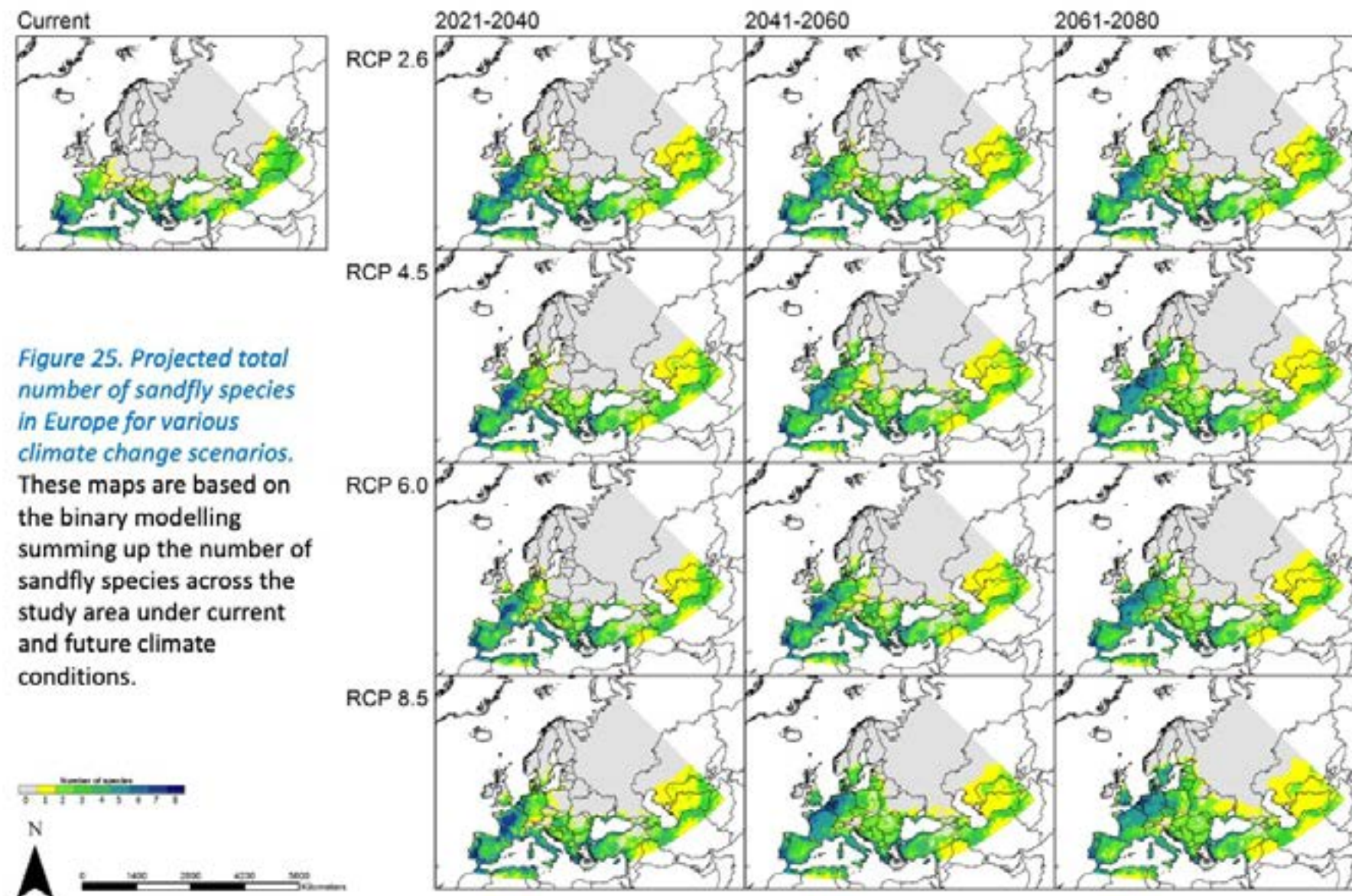
Table 4. Influence of altered climatic parameters on biological development of STHs associated with climate change. STHs = Soil-transmitted helminthiases, L₁-L₃ = larvae development stages

From: H.J. Weaver, J. M. Hawdon and E. P. Hoberg, "Soil-transmitted helminthiases: implications of climate change and human behavior", Trends in Parasitology, Dec 2010, **26**, (12), 574. <http://dx.doi.org/10.1016/j.pt.2010.06.009>

5.6 Climate change effects according to vector: Biting flies/bugs



Leishmaniasis and Sand Fly Fever/ Toscana Virus Infection



Onchocerciasis

Onchocerciasis occurs in sub-Saharan Africa, Central and South America and Yemen and relies on *Simulium* species of flies for vector transmission.

Increased temperature could increase the vector development rate as well as the development of *O. volvulus* larvae within the vector, but past a thermotolerant point, increased temperature resulted in increased vector mortality.

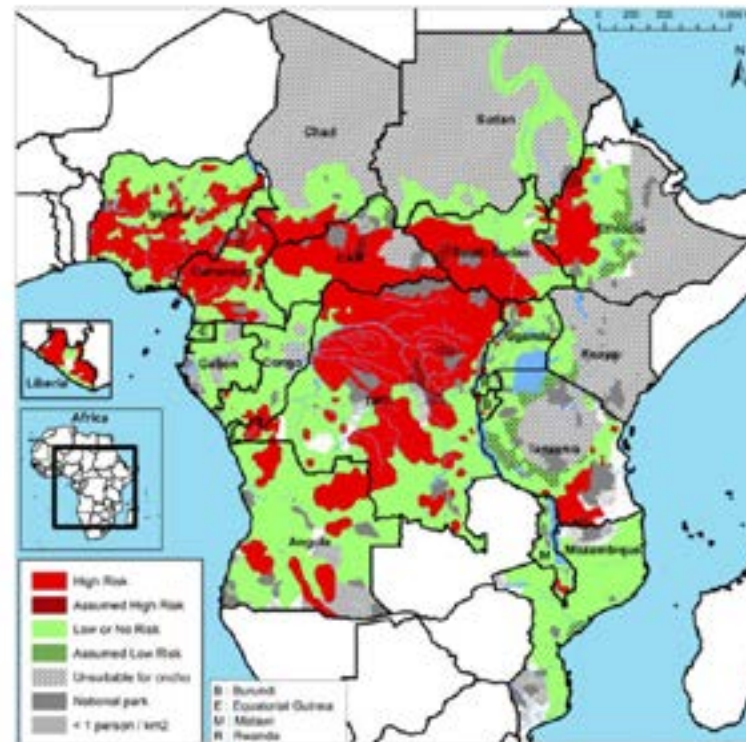


Figure 26. High risk and low risk areas of Onchocerciasis

At the time of writing, there were no original research publications available that considered the potential for long-term climate change to influence future transmission of this NTD [neglected tropical disease].

From: M. Booth, Chapter 3: "Climate Change and the Neglected Tropical Diseases", in *Advances in Parasitology*, Volume 100, (2018), p.86.

→ | <https://doi.org/10.1016/bs.apar.2018.02.001>

The authors acknowledged in this record that modelling and field data provided conflicting conclusions, with field data suggesting a decrease in future vector population and modelling suggesting increased transmission rates with increased future temperatures.

From: R. Tidman, B. Abela-Ridder, and R. Ruiz de Castañeda, "The impact of climate change on neglected tropical diseases: a systematic review", *Trans R Soc Trop Med Hyg* 2021, 115, 147-168

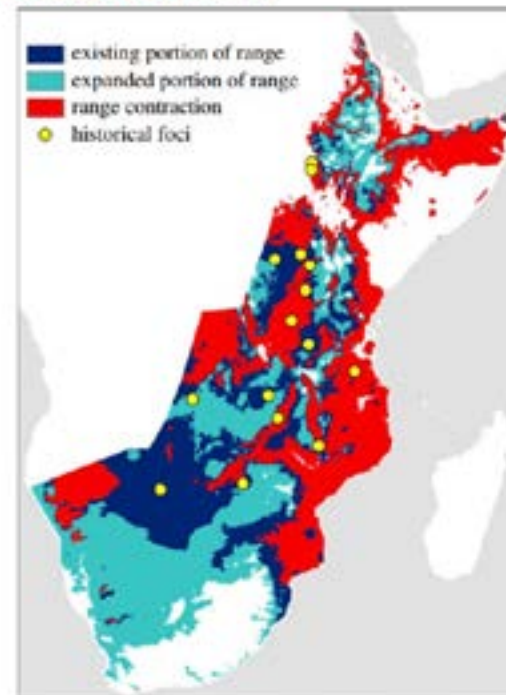
→ | <https://doi.org/10.1093/trstmh/traa192>

The fact that over 60 sibling species or cytoforms [of the blackfly *Simulium damnosum*] have been identified, each with different life history parameters, makes any attempt at projecting the effects of climate change highly challenging. Nonetheless it has been possible....to estimate how changing temperatures can affect the development of each stage of the vector, the development of *Onchocerca* within the fly, fly fecundity and the mortality rate of the fly. Unlike some other vector species, there appears to be no threshold temperature (within the range 15-32°C) at which point either fly mortality increases or the rate of development of the parasite decreases. Fluctuations in daily temperatures may affect the overall development time, corresponding to seasonal fluctuations in fly abundance....

Trypanosomiasis (African sleeping sickness) and Chagas disease (American trypanosomiasis)

Modelling of the effects of climate change on trypanosomiasis, found only in sub-Saharan Africa, has shown both range expansion and contraction as a result of predicted climate change temperature increase scenarios.

Figure 27. Suitable geographical range for *Trypanosoma brucei rhodesiense* transmission in 2050 (under the A2 emissions scenario using the CCSM3 global circulation model).



From: S. Moore, S. Shewchuk, K. W. Tindimuna and H. Young, "Predicting the effect of climate change on African trypanosomiasis: integrating epidemiology with parasite and vector biology", *J. R. Soc. Interface* (2012) 9: 812. <https://royalsocietypublishing.org/doi/10.1098/rsif.2011.0244>

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Similar effects have been found for Chagas disease in North and South America:

Both Chagas disease distribution and transmission risk are expected to change with changing environmental conditions associated with climate change, yet trends do not necessarily go in the same direction and will vary geographically across the Americas. Chile is predicted to have a slight reduction in some areas and expansion to other areas. A possible northeast shift of the disease was discussed for the USA, while an increased number of people are anticipated to be at risk from vector exposure in Mexico. Venezuela may

see a decreasing trend in Chagas disease cases, as vector distribution changes result in

fewer locations where humans are exposed to triatome vectors.

From: R. Tidman, B. Abela-Ridder, and R. Ruiz de Castañeda, "The impact of climate change on neglected tropical diseases: a systematic review", *Trans. R. Soc. Trop. Med. Hyg.*, 2021, 115, 147-168.

→ | <https://doi.org/10.1093/trstmh/traa192>

5.7 Summary of current state of knowledge of climate change effects on VBDs

Disease/vector	Change in geographical range/occurrence frequency/seasonal duration?	Main mechanism(s) of disease spread over large distances	Areas affected
Babesiosis/ticks	Yes	Reservoir hosts	Northern Europe/Scandinavia
Bubonic plague/fleas	No evidence to date	Reservoir hosts	None
Chagas disease (American trypanosomiasis)/triatomine bugs	Range and occurrence frequency changes	Reservoir hosts	North and South America
Chikungunya/mosquitoes	Yes	Human travel	Southern and western Europe, Mediterranean coastal areas
Crimean-Congo haemorrhagic fever/ticks	Yes	Reservoir hosts, human travel, trade in domestic animals	Western Europe/Spain
Dengue fever/mosquitoes	Increased occurrence frequency	Human travel	Mediterranean and Adriatic coastal areas, northern Italy.
Hookworm infection/snails	Yes	Human travel	Industrialised regions, boreal and temperate latitudes.
Japanese encephalitis/mosquitoes	Yes	Reservoir hosts, human travel, trade in domestic animals	All European areas that are suitable for <i>Culex</i> mosquitoes.
Leishmaniasis/sand flies	Yes	Reservoir hosts Human travel	Britain, northern and eastern Europe
Lyme disease/ticks	Northward range shift Decreased occurrence in south	Reservoir hosts	Northern Europe
Lymphatic filariasis/mosquitoes	Range shift to north and south Occurrence increase due to population growth	Human travel	Africa and Yemen
Malaria/mosquitoes	Yes	Human travel	Areas suitable for <i>Anopheles</i> mosquitoes. In Europe: all of southern and eastern Europe.

Table 5. Climate change effects on VBDs: summary

Summary (contd.)

Disease	Change in geographical range/occurrence frequency/seasonal duration?	Main mechanism of disease spread over large distances	Areas affected
Onchocerciasis (river blindness)/blackflies	Possible increased occurrence frequency	Human travel	Africa
Rift Valley fever/mosquitoes	Yes	Trade in domestic animals	Mediterranean basin, central Europe, and Middle East
Schistosomiasis (bilharziasis)/snails	Range shifts to less hot areas	Human travel	Southern Europe, Africa and Middle East
Sleeping sickness (African trypanosomiasis)/tsetse flies	Range shifts	Reservoir hosts	Sub-Saharan Africa
Tick-borne encephalitis/ticks	Northwest range shift	Reservoir hosts	Brittany, southwest England, Ireland
Toscana virus infection/sand fly fever/sand flies	Yes	Reservoir hosts Human travel	Britain, northern and eastern Europe
Tungiasis/fleas	Yes	Human travel	Developed countries
Typhus/fleas	Increased occurrence frequency	Reservoir hosts	Temperate regions
West Nile fever/mosquitoes	Yes	Reservoir hosts	Western Europe
Yellow fever/mosquitoes	Yes	Reservoir hosts	Southern Europe
Zika/mosquitoes	Yes	Human travel	Areas suitable for <i>Aedes</i> and <i>Culex</i> mosquitoes in Europe and North America

Table 5 (contd.)

6. Possible prevention and mitigation methods

It should be apparent from table 5 above that many areas of the world, including Europe, are at risk of VBD epidemics as a result of climate change.

Methods for avoiding or ameliorating these effects can be grouped in three broad categories:

- Environmental
- Societal
- Technological



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6.1 Environmental VBD control methods

Aside from the obvious mitigation by a global reduction in greenhouse gas emissions, a number of other environmental aspects can be considered of importance:

→ Land management to prevent favourable conditions for the establishment of vector species in the aftermath of extreme weather events, e.g. avoidance of the formation of bodies of lying water to prevent mosquito breeding as a result of flooding/increased precipitation.

6.2 Societal VBD control methods

→ Implementation of VBD surveillance in areas at risk.
→ Enhancement of public awareness of VBD threats:

1. Education programmes in schools and colleges.
2. Public information campaigns in conventional and social media.
3. Real-time VBD information by mobile personal health apps, e.g. along the lines of the national COVID Tracker apps developed within the EU. Could these be

integrated into a single EU health app with a section for VBDs?

- Improved public access to medical treatment and vaccines for VBDs.
- Effective travel controls on people and animals moving from infected areas.
- Development of domestic animal management methods to eliminate contact with vectors/wild reservoir host species.

6.3 Technological VBD control methods

- Vector elimination/containment by biological, mechanical, and chemical means.
- Development of fast, cheap, readily available VBD tests.
- Improved modelling methods to predict climate change-VBD risks.
- Production of effective vaccines for all VBDs: only 26% of the VBD diseases discussed here have vaccines currently available (see table 6).

Table 6. Current status of VBD vaccine development

Disease	Vaccine available?	Vaccine under development?
Babesiosis	No	No
Bubonic plague	Yes	-
Chagas disease (American trypanosomiasis)	No	Yes
Chikungunya	No	Yes
Crimean-Congo haemorrhagic fever	No	Yes
Dengue fever	Yes	-
Hookworm infection	No	Yes
Japanese encephalitis	Yes	-
Leishmaniasis	No	Yes
Lyme disease	No	Yes
Lymphatic filariasis	No	Yes
Malaria	Yes	-

Disease	Vaccine available?	Vaccine under development?
Onchocerciasis (river blindness)	No	Yes
Rift Valley fever	No	Yes
Schistosomiasis (bilharziasis)	No	Yes
Sleeping sickness (African trypanosomiasis)	No	Yes
Tick-borne encephalitis	Yes	-
Toscana virus infection/sand fly fever	No	No
Tungiasis	No	*N/a
Typhus	No	Yes
West Nile fever	No	Yes
Yellow fever	Yes	-
Zika	No	Yes

*Not applicable: pathogen is an insect

Only 26% (6/23) have a vaccine currently available.

7. Key take home messages

- Three groups of complex, interlinked and often poorly understood stressors influence the emergence and propagation of VBDs: anthropogenic climatic, demographic, and technological changes.
- Major anthropogenic climatic hazards for disease aggravation: warming, precipitation, floods, drought and storms.
- VBDs constitute the largest single aggravated disease group, with viruses and bacteria the largest pathogen groups.
- 22 out of 23 of the major VBDs examined, have been shown to or are predicted to show changes in geographical range, disease occurrence, and/or frequency/seasonal duration due to climate change.
- Of the climate change aggravated VBD vectors, mosquitoes constitute the largest type (39%), followed by ticks (22%), fleas (13%), snails (9%), and sand flies (9%).
- 18 of the 23 VBDs (78%) considered here, have been shown to or are predicted to affect areas of Europe.
- Prevention and mitigation of climate change-aggravated VBDs revolves around environmental, societal, and technological control methods, including:
 1. Improved VBD surveillance of the human and domestic animal reservoir host populations.
 2. Enhanced public awareness of VBD threats.
 3. Development of effective VBD vaccines.

8. Essential reading for this lesson

1. P.J. Hotez, "Southern Europe's Coming Plagues: Vector-Borne Neglected Tropical Diseases", PLoS Neglected Tropical Diseases, 2016, 10,(6), e0004243. <https://doi.org/10.1371/journal.pntd.0004243>.
2. J. Ma *et al.*, "Climate Change Drives the Transmission and Spread of Vector-Borne Diseases: An Ecological Perspective", Biology, 2022, 11, 1628. <https://doi.org/10.3390/biology11111628>.
3. J.N. Mills, "Potential Influence of Climate Change on Vector-Borne and Zoonotic Diseases: A Review and Proposed Research Plan", Environ. Health Perspectives, 2010, 118, 1507–1514. <https://doi.org/10.1289/ehp.0901389>.
4. J. Rocklöv and R. Dubrow, "Climate Change: An Enduring Challenge for Vector-borne Disease Prevention and Control", Nature Immunology, May 2020, 21, 479–483. <https://doi.org/10.1038/s41590-020-0648-y>.
5. W.K. Reisen, in "Climate Change and Public Health", by B. Levy and J. Patz, July 2015, chapter 6, 129-156, Oxford University Press. Online ISBN: 9780190202484, print ISBN: 9780190202453. <https://doi.org/10.1093/med/9780190202453.003.0007>.

9. Test your knowledge

1. What is a vector-borne disease?
2. What effects do VBDs have on global society?
3. List the three groups of stressors that influence the global landscape of VBD risk, in terms of their effects on pathogenesis, local-scale disease dynamics, and global spread. Give one stressor example from each group.
4. Explain how climate change factors affect VBD pathogenesis, local-scale disease dynamics, and global spread.
5. List three of the five most important climatic hazards that account for most cases of pathogenic disease aggravation.
6. Give one VBD example for each of the following vector types, explaining how climate change will aggravate the disease: (a) tick-borne; (b) mosquito-borne; (c) flea-borne; (d) snail-borne; (e) biting fly/bug-borne.
7. Give two examples of specific control methods for the prevention/mitigation of climate change aggravation of VBDs, from each of the following control groups:
 - Environmental control
 - Societal control
 - Technological control

Thank you for you attention!

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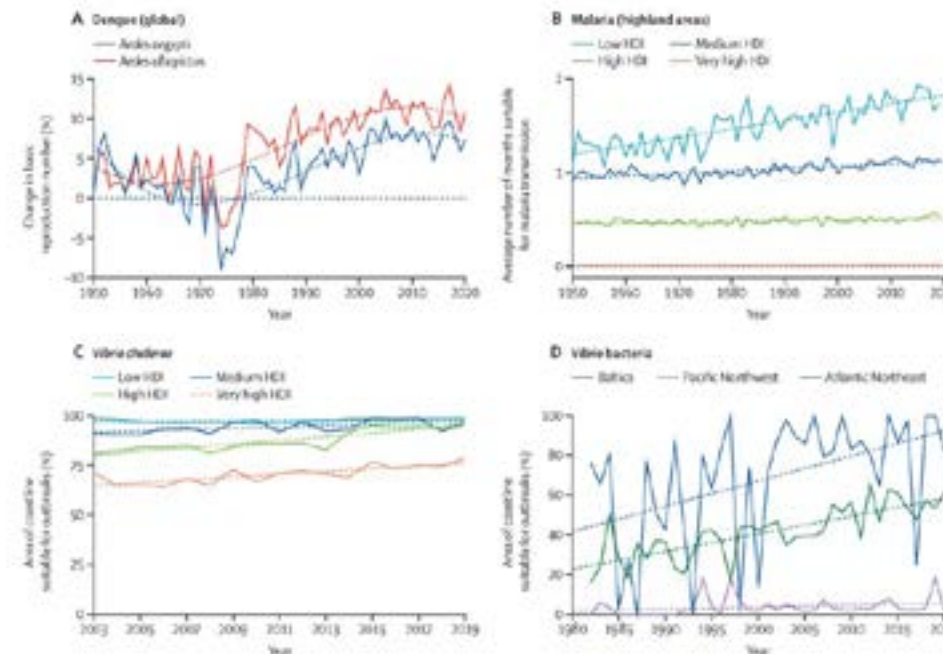
Impact of climate change on waterborne diseases, toxic algae, balneology

The 2021 report of the *Lancet* Countdown

1.3: climate-sensitive infectious diseases

1.3.1: climate suitability for infectious disease transmission

1.3.2: vulnerability to mosquito-borne diseases



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The diagrams of the Lancet Countdown 2021 Report calls attention to the relationship between climate change and infectious diseases.

and weather events, the risk of these infectious diseases will only worsen.

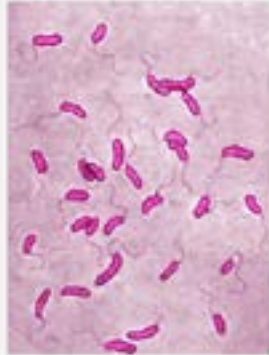
→ But there are actions we can take to reduce these risks.

What can cause waterborne diseases?

- drinking or coming into contact with contaminated water,
- contamination could be caused by man-made or natural pollutants, or faeces from an infected person or animal.
- Waterborne diseases like cholera and typhoid are still a leading cause of human morbidity and mortality worldwide. As climate change increasingly impacts global temperatures

Cholera

- Cholera: *spring* and *autumn* peaks



- *Vibrio cholerae*, a commensal of *copepods* that thrives in water along the coast and in large bodies of water inland.

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The disease appears in two different outbreak patterns

- endemic, in coastal areas directly influenced by tidal cycles, and
- epidemic, occurring more in inland areas (such as Delhi), which can go years without many cases and then experience a huge outbreak.
- The isolated strains of *V. cholerae* are other than the epidemic strain (serotype O1) that accounts for most of the major epidemics.
- *V. cholerae* as a species is highly subject to lateral gene transfer, the genes that code for toxin and other properties related to pathogenicity can easily be transferred to a strain that is more prevalent in the environment.

Cholera:

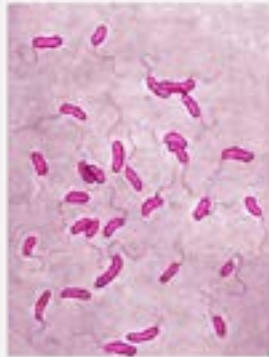
- consistent spring and autumn peaks of disease over a number of years.
- These peaks correspond with low river discharge in the spring, which allows bacteria-laden tidal seawater to wash in, and high river discharge in the autumn, leading to the cross-contamination of water supplies.
- *Vibrio cholerae*, a commensal of copepods that thrives in water along the coast and in large bodies of water inland.
- WHO: *V. cholerae* infects 3-5 million pers./yr (diarrhea); death: 100 000/yr globally.

The causes of cholera outbreaks:

- Hot weather and above-average rainfall in the context of poor infrastructure and crowding.
- The main host: copepod (zooplankton).
- Warmer nutrient-rich waters support thriving populations of phytoplankton, consequently leading to a bloom of zooplankton.
- It can never be eradicated, because the host is an integral part of the environment.

Cholera

- Cholera: *spring* and *autumn* peaks



- *Vibrio cholerae*, a commensal of *copepods* that thrives in water along the coast and in large bodies of water inland.

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The sea surface temperature (SST) of enclosed bodies of water and estuaries has increased more rapidly as a result of climate change than that of oceans

→ Elevated SST in brackish water provides ideal environmental growth conditions for *Vibrio* species

→ These conditions can be found during the summer months in areas of water with moderate salinity such as the Baltic Sea, or the East China Sea around Shanghai.

→ For example, the number of *Vibrio* cases around the Baltic Sea has been found to increase in line with a rise in SST during

the summers of 5 years.. elevated SST across much of the Baltic Sea was associated with reported *Vibrio*-associated illness.

→ In contrast, open ocean environments do

not usually

provide

suitable

- High rainfall can increase the risk of wastewater contaminating either raw or treated water (person-to-environment transmission).
- While low rainfall can increase the concentration of pathogens in water (environment-to-person transmission).

→ A study in Bangladesh found that the number of cholera cases increased by 14% when rainfall increased by 10mm above the rainfall threshold.

growth conditions for these bacteria due to their high salinity, low temperature, and limited nutrient content.

Climate Variability and the Outbreaks of Cholera in Zanzibar, East Africa: A Time Series Analysis

→ A 1°C increase in temperature at 4 months lag resulted in a 2-fold increase of cholera cases, and an increase of 200 mm of rainfall at 2 months lag resulted in a 1.6-fold increase of cholera cases. Temperature and rainfall interaction yielded a significantly positive association with cholera at a 1-month lag.

Rainfall and cholera

→ Rainfall also has a direct influence on the transmission of cholera.

Cholera isn't the only waterborne disease impacted by high temperature, heavy rain and drought.

→ Increases in ambient temperature are linked to more cases of diarrheagenic *Escherichia coli*.

- 8% increase in the incidence of diarrheagenic *E. coli* for each 1°C increase in mean monthly temperature.
- In the Pacific islands leptospirosis, typhoid and dengue are three water-related diseases influenced by environmental factors were studied.

→ Cases of typhoid are more likely to occur in areas that have experienced flooding of a stream or river.

Cholera isn't the only waterborne disease impacted by high temperature, heavy rain and drought

- Leptospirosis (*Leptospira sp.*)
- Dengue fever
- Diarrhea (*diarrheagenic Escherichia coli*)
- Typhoid fever (*Salmonella enterica ssp. enterica serovar. Typhi*) (*S.Typhi*)

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Typhoid (fever)

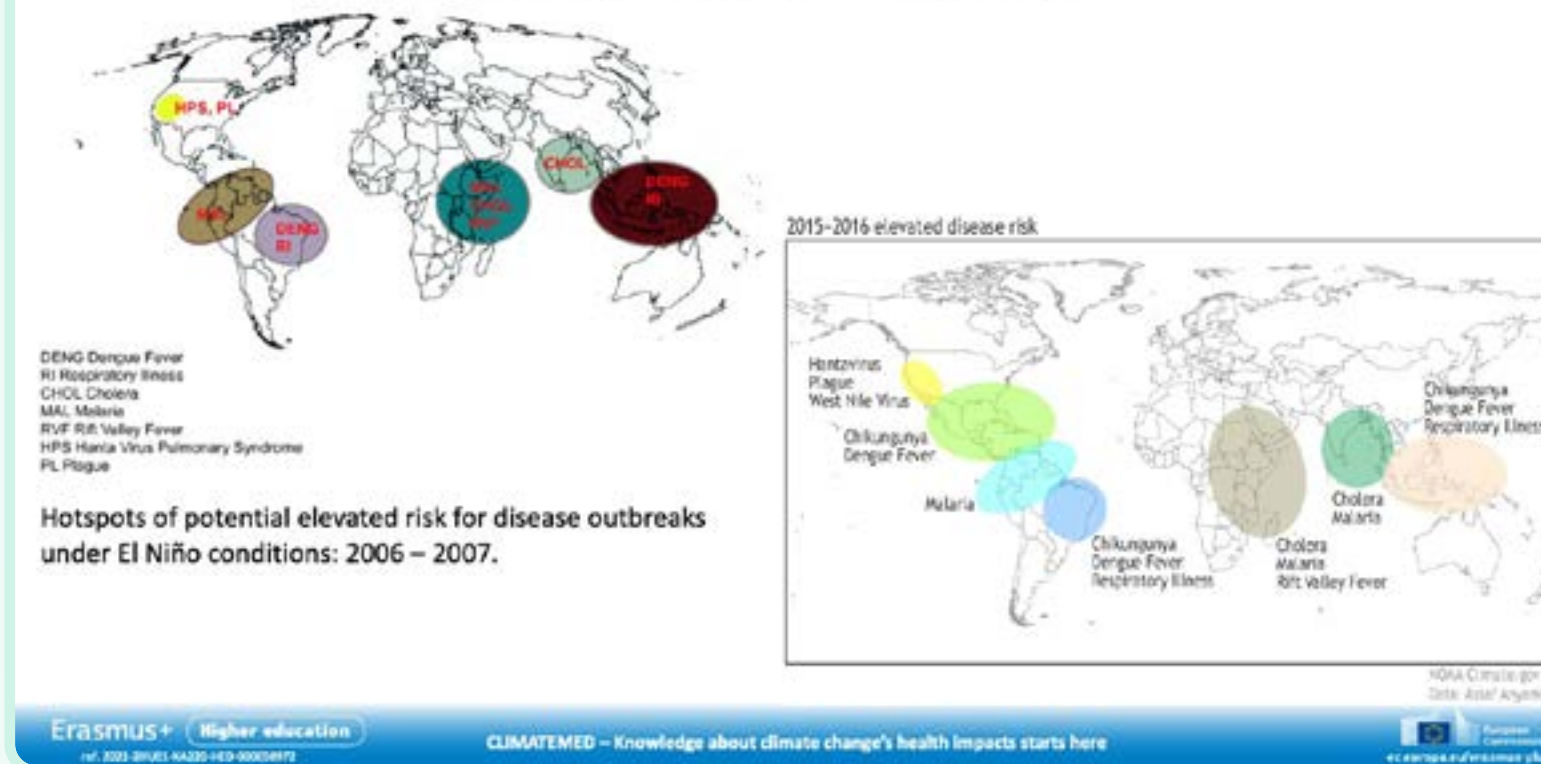
Affects children and adolescents in low- and middle-income countries.

- Global Burden of Disease study: in 2017 nearly 11 million cases and more than 116,000 deaths due to typhoid worldwide.
- However, the burden is likely underestimated due to difficulties with surveillance and diagnostics.

Intervention

- Create the policy and requisite budget for quickly procuring and administering typhoid conjugate vaccines (TCVs) to protect impacted communities when extreme weather events do occur.
- Introduce TCVs to help protect populations most at risk from severe weather events.
- Educate decision-makers, national and sub-national leaders, and other health
- influencers about the detrimental impact of climate change and the importance of protecting vulnerable communities against increases in typhoid transmission.

El Niño and disease outbreaks



Dengue fever

Vectors:

- *Aedes aegypti*
- *Aedes albopictus*
- *Aedes polynesiensis*
- several species of the *Aedes scutellaris* complex

Pathogen:

- Dengue fever virus (DENV 1-4), RNA virus of the family Flaviviridae; genus Flavivirus

Waterborne diseases in changing climate

- Projected increase in the risk of malaria for eastern, central and southern Africa.
- In eastern Africa, estimates of additional people at risk range from 40–80 million with 2°C warming and around 70–170 million with 4°C warming.
- Malaria is already spreading to the highlands of Ethiopia, Kenya, Rwanda and Burundi, where it previously was not present.
- The 2015-2016 Zika outbreak in the Americas was likely partially due to favorable climate conditions caused by El Niño that allowed the disease, which was likely introduced to Brazil in 2013, to spread.

Mosquito-borne diseases

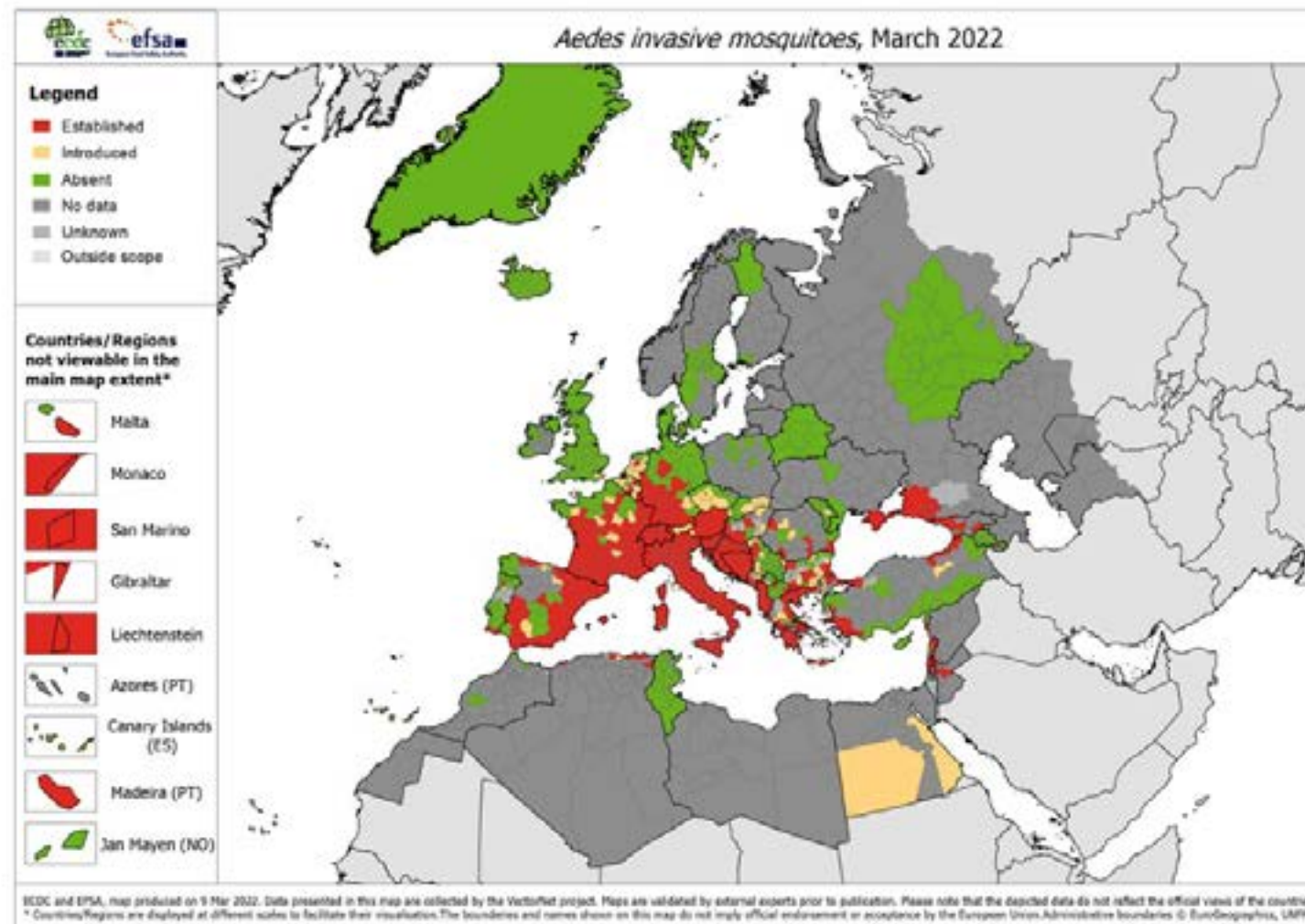
- Zika virus disease (Zika) is caused by the Zika virus and is spread to people primarily from the bite of an infected *Aedes* sp. mosquito. These mosquitoes bite most actively in the daytime but also bite at night. There is currently no vaccine to prevent Zika infection.
- *Culex* sp.: The most common way the West Nile virus is transmitted to victims by the bite of a mosquito. Most people infected with West Nile virus will not have any symptoms. About 1 in 5 people who are infected will develop a fever and other symptoms. Less than 1% of those infected develop a serious, sometimes fatal, neurologic illness.

Mosquitoborne viral diseases (Zika)

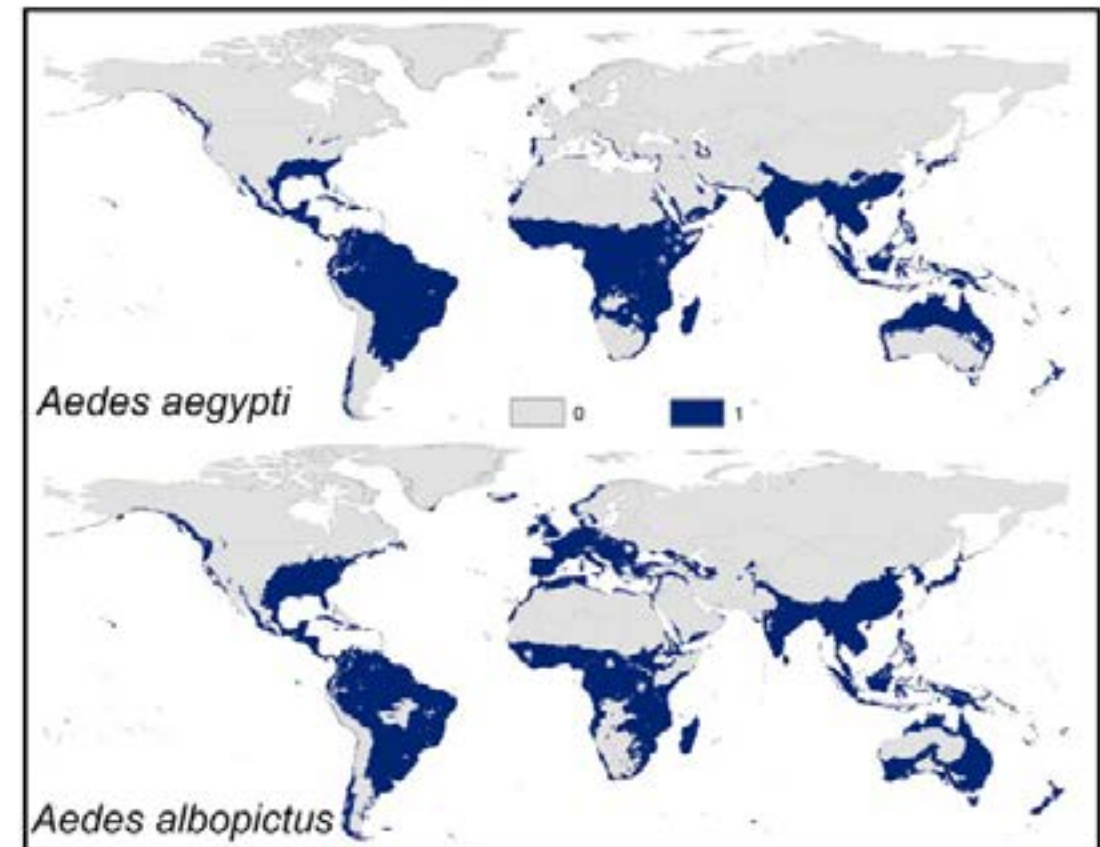
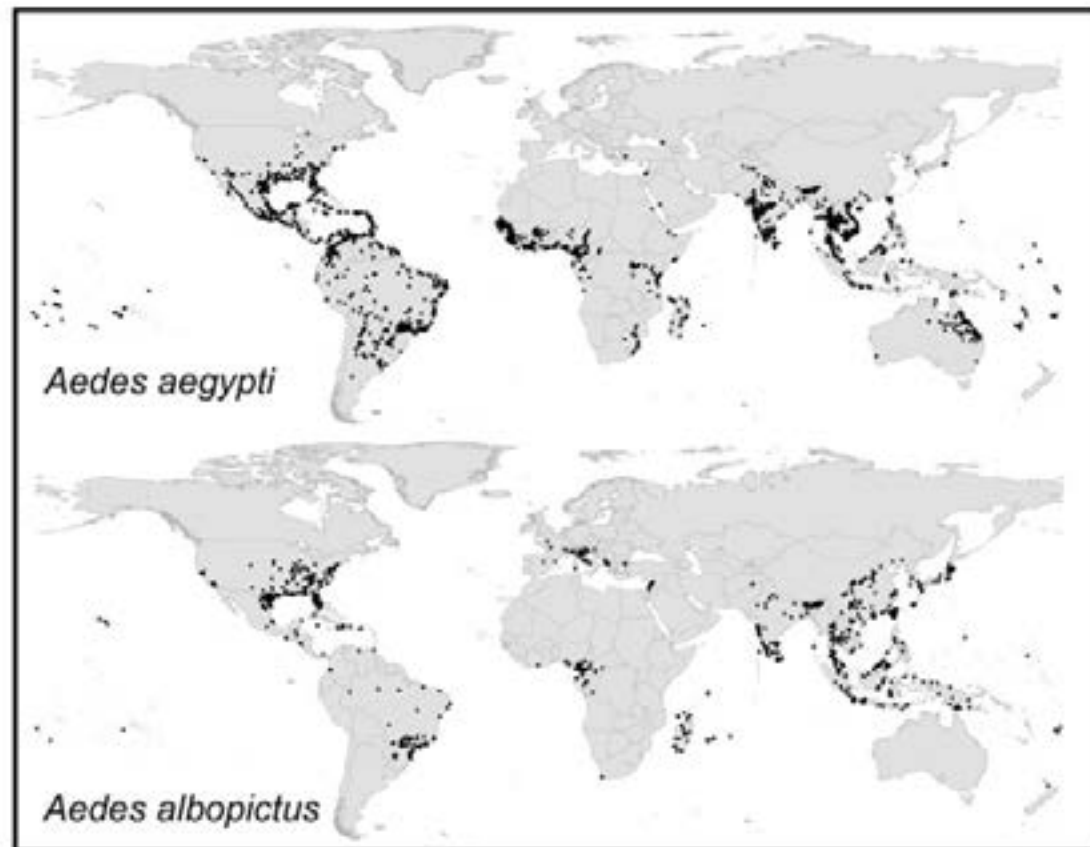
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- ***Aedes egypti***



The map shows the current known distribution of *Aedes* invasive mosquitoes (*Ae. aegypti*, *Ae. albopictus*, *Ae. atropalpus*, *Ae. japonicus* and *Ae. koreicus*) in Europe as of March 2022.



Geographical distribution of *Aedes* spp. (present – expected)



SPECIES NAME/CLASSIFICATION: *Aedes (Stegomyia) albopictus* **COMMON NAME:** Asian tiger mosquito, Forest day mosquito **SYNONYMS AND OTHER NAME IN USE:** *Stegomyia albopicta*



→ This mosquito species is a known vector of chikungunya virus, dengue virus and dirofilariasis. A number of other viruses affecting human health have also been isolated from field-collected *Ae. albopictus* in different countries. Moreover, its recent involvement in the localised transmission of chikungunya virus in Italy and France and dengue virus in France and Croatia highlights the importance of monitoring this invasive species.

Other water-related, mosquito-borne viruses:

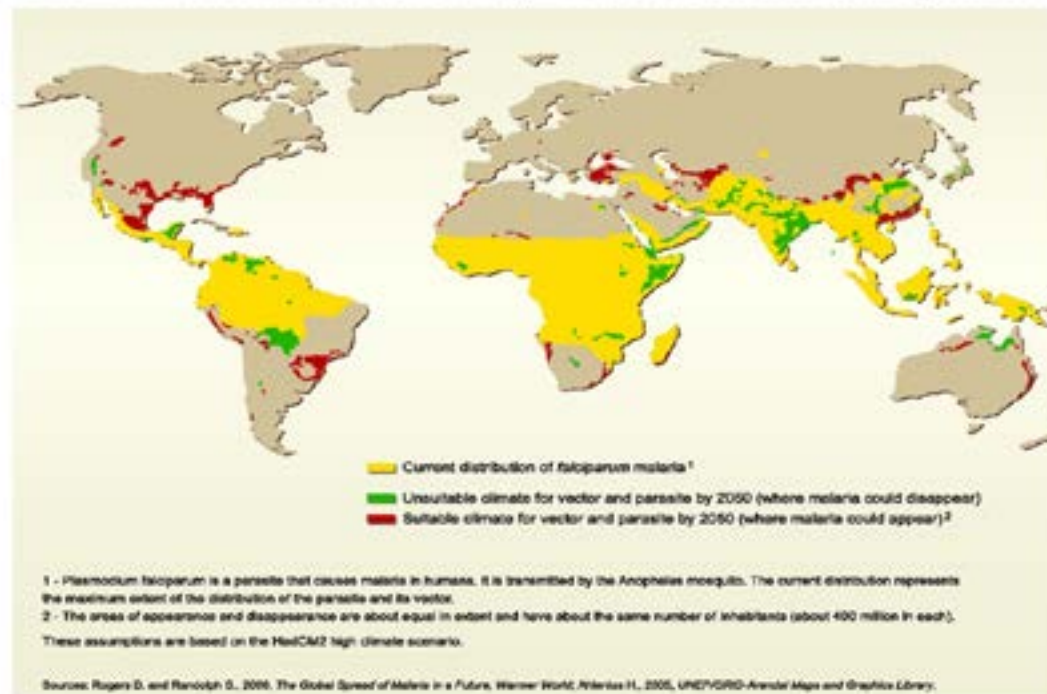
- Chikungunya Virus
- Eastern Equine Encephalitis Virus
- Japanese Encephalitis Virus
- La Crosse Encephalitis
- St. Louis Encephalitis
- Yellow Fever
- Etc.

It is now possible to relate vector-borne infectious disease patterns directly to climate.
(Rita Corwell, Johns Hopkins Univ.)

Aedes albopictus

- *Aedes albopictus* has undergone a dramatic global expansion facilitated by human activities
- It is now listed as one of the top 100 invasive species by the Invasive Species Specialist Group
- Climate change predictions suggest *Ae. albopictus* will continue to be a successful invasive species that will spread beyond its current geographical boundaries

Distribution of malaria caused by *Plasmodium falciparum* by 2050



There are vaccines that can prevent malaria, a mosquito-borne infectious disease which annually affects an estimated 247 million people worldwide and causes 619,000 deaths. The first approved vaccine for malaria is RTS,S, known by the brand name Mosquirix. As of April 2023, the vaccine has been given to 1.5 million children living in areas with moderate-to-high malaria transmission. It requires at least three doses in infants by age 2, and a fourth dose extends the protection for another 1-2 years. The vaccine reduces hospital admissions from severe malaria by around 30%.

Malaria

The most abundant infectious parasitic disease on Earth (some 200 million patients each year, killing more than 600,000).

Its distribution area is continuously increasing with the global warming, both vertically (higher altitudes) and horizontally (more new countries are involved).

Malaria is caused by infection with parasites in the genus *Plasmodium*. Vector: *Anopheles* sp. mosquitoes

In humans, malaria is caused by six *Plasmodium* species: *P. falciparum*, *P. malariae*, *P. ovale curtisi*, *P. ovale wallikeri*, *P. vivax* and *P. knowlesi*.

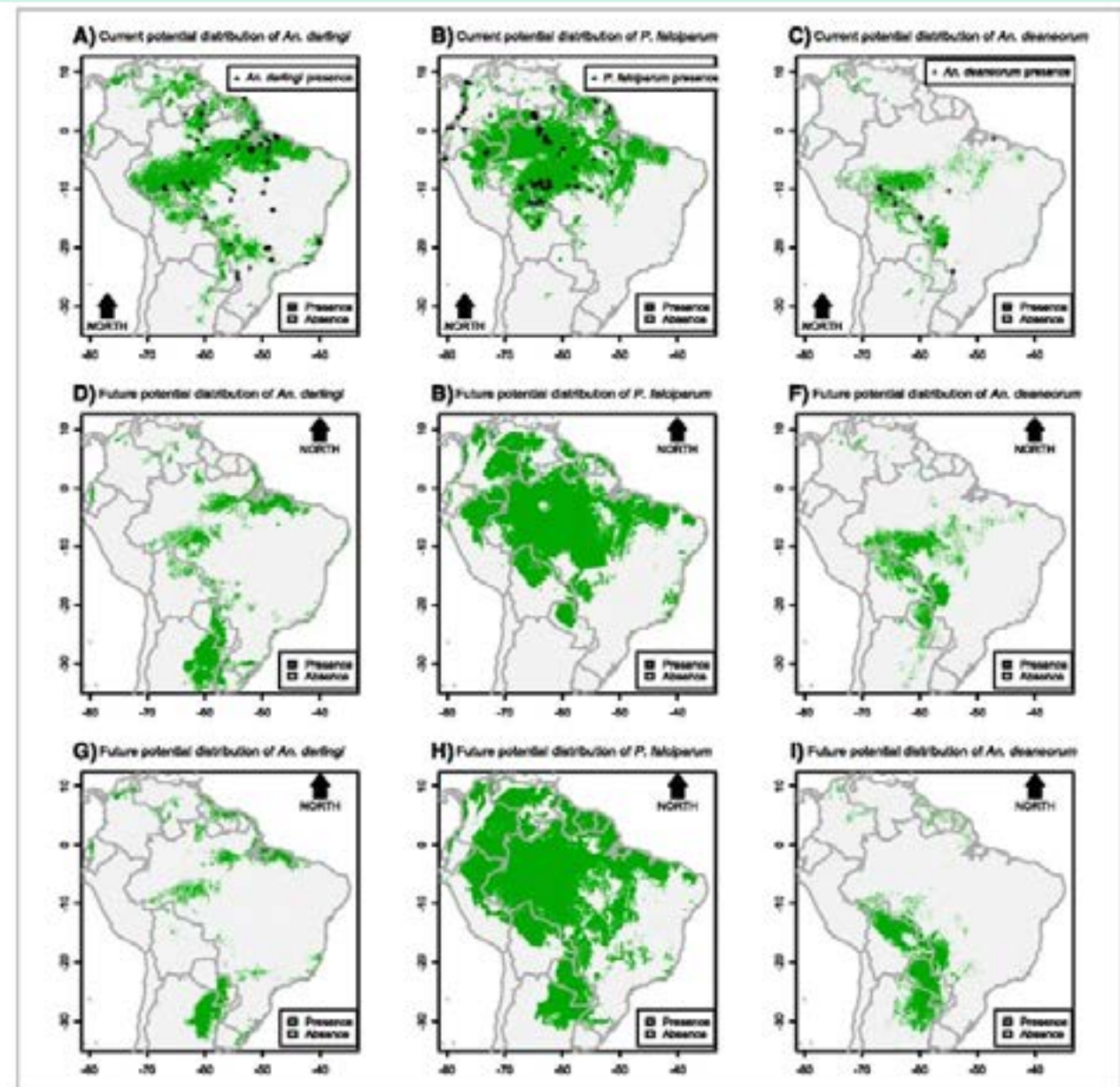
Among those infected, *P. falciparum* is the most common species identified (~75%) followed by *P. vivax* (~20%). Although *P. falciparum* traditionally accounts for the majority of deaths, recent evidence suggests that *P. vivax* malaria is associated with potentially life-threatening conditions about as often as with a diagnosis of *P. falciparum* infection. *P. vivax* proportionally is more common outside Africa.

Potential distribution of *Anopheles darlingi*,
Plasmodium falciparum and
An. deaneorum (in S. America) under:

contemporary conditions,

global climate change
scenario #1, and

global climate change
scenario #2



Climate change affects:

- Survival and reproduction rate of the vector
- Vector activity, the biting rate
- Rate of development and reproduction of the pathogen within the vector

Increasing temperature:

- Horizontal habitat expansion
- Vertical habitat expansion

Climate change and waterborne intoxications

- Toxic algae and cyanobacteria



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→ Coastal upwelling

Excess nutrients from the sea floor

Marine toxic HABs/Seafood-borne diseases

→ Ciguatera poisoning (incidence: 251/10,000) in Pacific and Caribbean populations

Frequent human fatalities:

- Amnesic Shellfish Poisoning (Domoic acid)
- Ciguatera Poisoning (Ciguatoxin)
- Palytoxicosis (Palytoxin)
- Paralytic Shellfish Poisoning (Saxitoxin)

Harmful Algal Blooms (HABs) and Health

→ Acute or chronic human health effects - impacts of natural phycotoxins via:

- Ingestion of contaminated food
- Water consumption
- Inhalation
- Direct skin contact

- Small organisms move easier - floating the surface faster
- Algal blooms absorb sunlight - acceleration (even warmer water, promoting blooms)
- Changes in salinity
 - Saltier freshwater - invasion of marine algae
- Higher CO₂ levels
- Changes in rainfall

Climate impacts:

Warming water temperature

- Toxic algae prefer warmer water
- Prevents water from mixing - algae grow thicker and faster

- Alternating periods of drought and intense storms - nutrient runoff into waterbodies



Climate change and waterborne intoxications

- Toxic algae and cyanobacteria



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Ciguatera fish poisoning (CFP)

- the most common nonbacterial illness linked with eating fish, arises from the ciguatoxin produced by Gambierdiscus algae in tropical and subtropical areas
- relationship between climate variability and reports of CFP: incidence of CFP is likely to increase with rises in sea-surface temperature and tropical storm frequency.
- Ciguatoxin bioaccumulates up the food chain as herbivorous fish eat the algae and are themselves eaten by carnivorous fish.
- The odorless, tasteless toxin withstands freezing and cooking, consumers show gastrointestinal, neurological, and sometimes

cardiovascular symptoms within hours of exposure.

- An estimated 50,000–500,000 cases of CFP occur annually worldwide. CFP is thought to be a widely unreported illness.

Marine toxic HABs/Seafood-borne diseases

Ciguatera poisoning (incidence: 251/10,000) in Pacific and Caribbean populations

Frequent human fatalities:

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Young N et al. Marine harmful algal blooms and human health:
A systematic scoping review. Harmful Algae 98 (2020) 101901



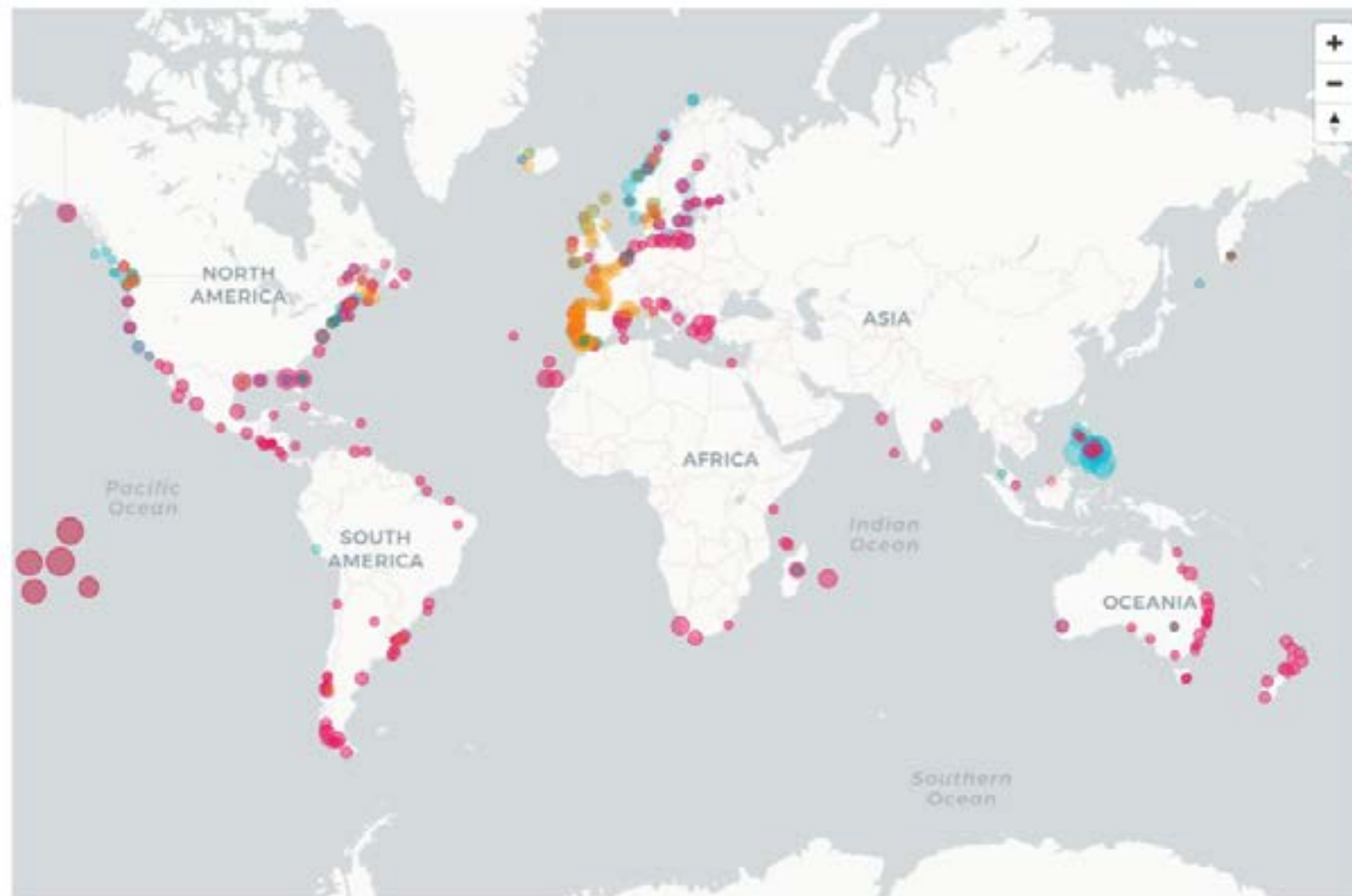
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IOC-UNESCO Harmful Algal Information System

All syndromes/Human/Marine



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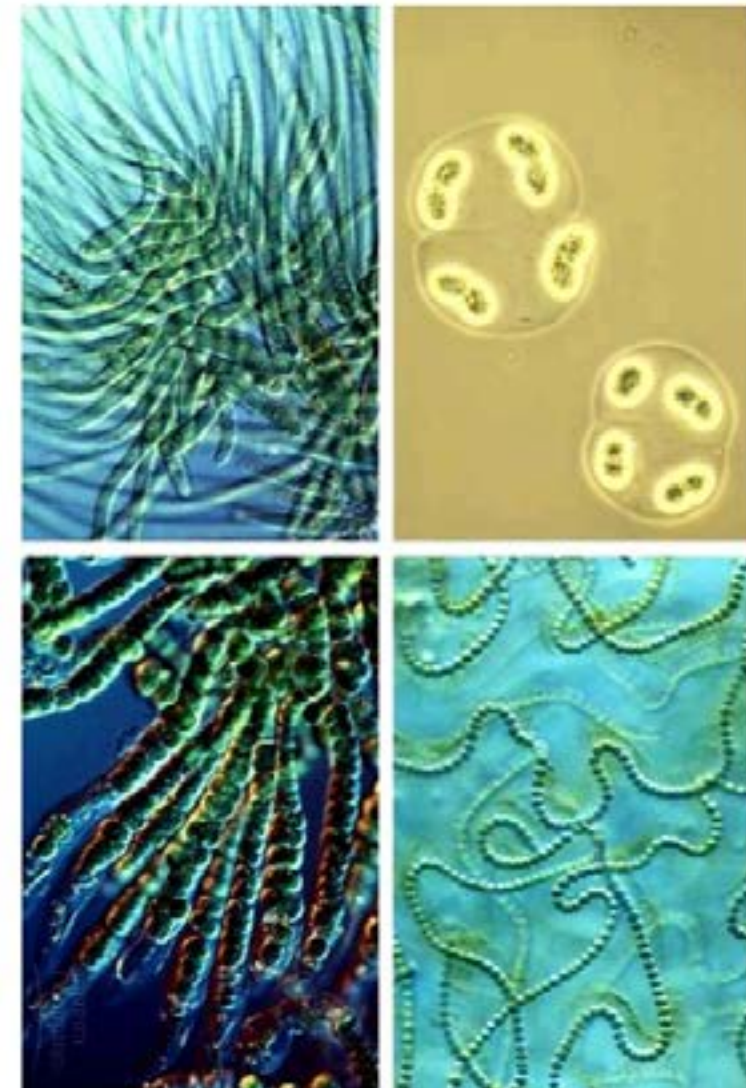
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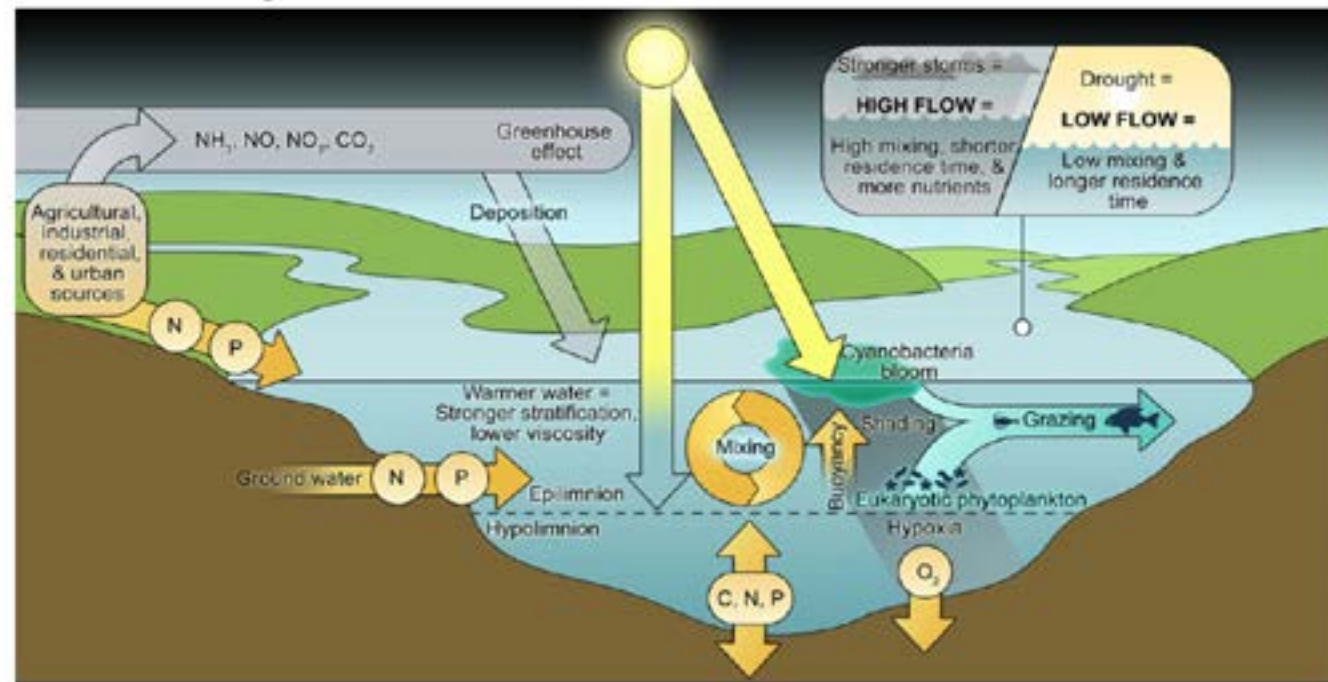
What are Cyanobacteria?

New taxonomy: formerly blue-green algae

- **prokaryotes**
- **photosynthesizing**
- **Gram negative cell wall**
- **unicellular**
- **filamentous**



Multiple interacting environmental factors controlling CyanoHABs in freshwater ecosystems (Paerl 2017)



- Synthesis of UV-screening/absorbing compounds
- Vitamins from the coexisting bacteria

Cyanobacterial harmful blooms (CyanoHABs) in freshwater ecosystems

→ Cyanobacteria (among the most ancient phototrophs on Earth)

- Long evolutionary history, continuous adaptation to:
- Geochemical and climatic changes
- Anthropogenic (human and climatic) modifications of aquatic ecosystems, like
 - nutrient over-enrichment
 - hydrologic modifications
 - global warming

CyanoHAB genera are controlled by the synergistic effects of nutrient (N and P) supplies, light, temperature, water residence/flushing times, and biotic interactions.

Accordingly, mitigation strategies are focused on manipulating these dynamic factors.

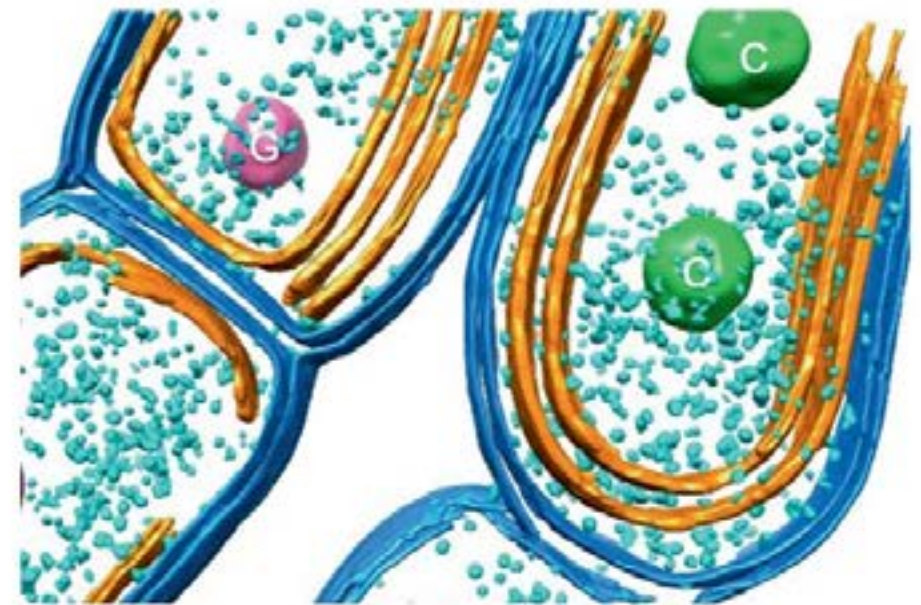
Specific features:

- UV-tolerance
 - antioxidant production,
 - DNA repair, protein-resynthesis,
 - apoptosis,

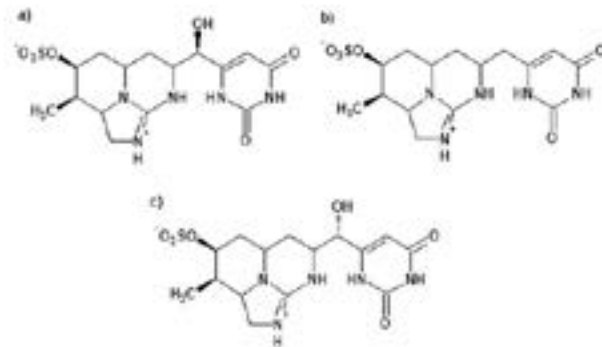
Carbon sources

- Photosynthesis: organic compounds from inorganic carbon
- Aquatic organisms: availability of inorganic carbon from diluted CO_2 gas, carbonate or bicarbonate anions
- Using carboxysomes which are bacterial compartments with specific enzymes

Cyanobacterial thylakoid membrane
(C: carboxysome, the site of CO_2 fixation)



Cyanobacterial toxins, examples

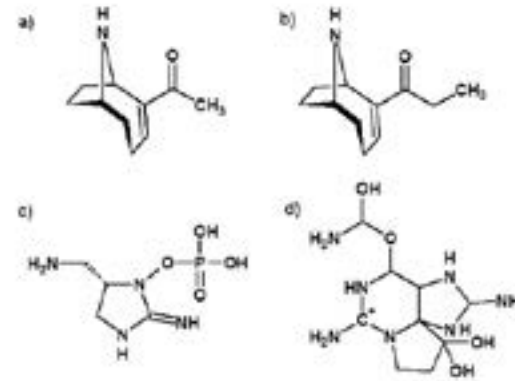


Cytotoxic alkaloids:

- a) cylindrospermopsin;
- b) deoxycylindrospermopsin;
- c) 7-epicylindrospermopsin.

Neurotoxins:

- a) anatoxin-a;
- b) homoanatoxin-a;
- c) anatoxin-a(S);
- d) saxitoxin



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Direct exposure to algae/toxins

Drinking water

→ Palm Island Mystery Disease, Australia (1979)

→ Gastroenteritis, diarrhea, vomiting,
kidney failure, etc.

→ Disinfection byproducts of drinking water
treatment

→ Dioxin production

Bathing/swimming (skin contact, swallowing)

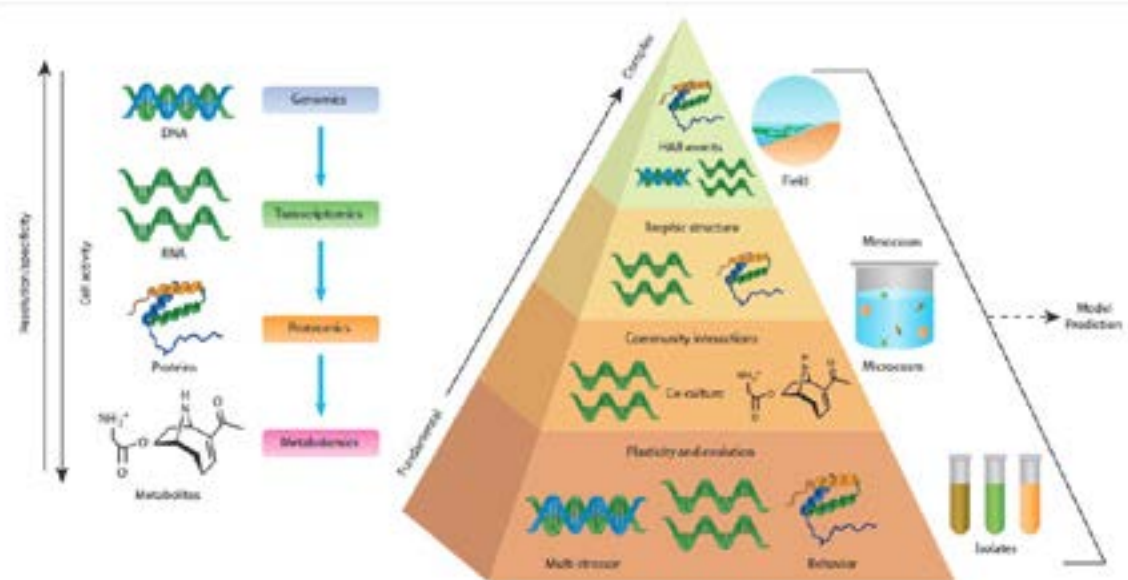
→ Rashes

→ Stomach or liver illness

→ Respiratory problems

→ Neurological effects

Experimental and field studies to determine the impacts of climate change. Role of omics



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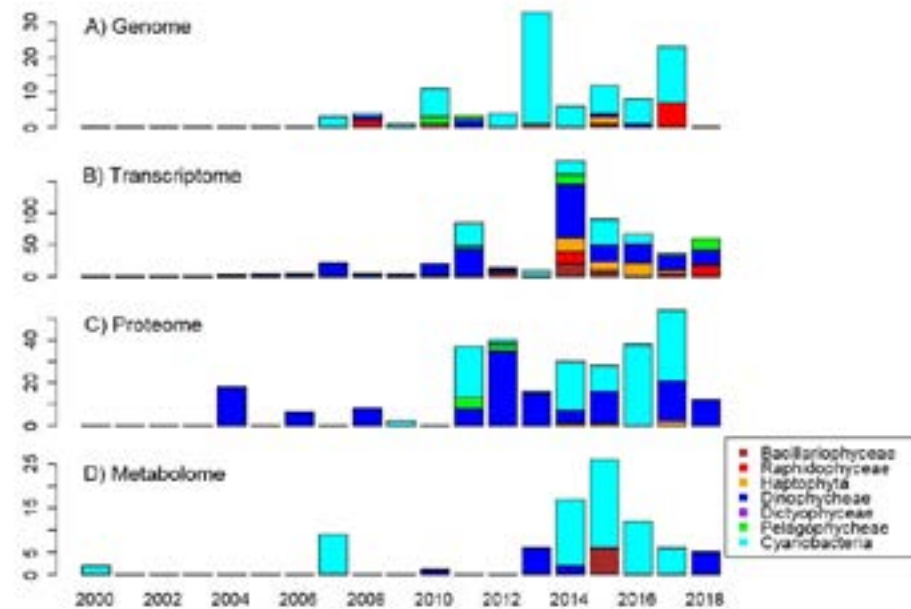
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The new field of „omics” including:

- genomics
- transcriptomics
- proteomics
- metabolomics

in studying relationship of climate change and
HAB events in saline and fresh waters.

Published or accessible omics data on HAB causing taxa



Taxa causing HABs published in the scientific literature.

Take-home messages

What can be done to reduce the risk of waterborne diseases?

- provide universal access to care and disease management
- improve disease surveillance
- develop and invest in early warning systems to monitor changes in climatic conditions
- upgrade water catchment, storage, treatment and distribution systems
- protect critical infrastructure from floods, storms and sea level rise
- limit water overuse
- use household water purification systems

Suggested literature

2021 report of the Lancet Countdown on health and climate change

[https://www.thelancet.com/article/S0140-6736\(21\)01787-6/fulltext](https://www.thelancet.com/article/S0140-6736(21)01787-6/fulltext)

Hennon GMM, Dyhrman ST: Progress and promise of omics for predicting the impacts of climate change on harmful algal blooms. **Harmful Algae** 91 (2020) 101587

Climate change 2022: Impacts, adaptation, vulnerability (IPCC Report)

<https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/>

Test your knowledge

1. What does "waterborne" disease mean?
2. Which infectious diseases are in close correlation to climate change?
3. Which waterborne diseases are in correlation to climate change?
4. Which methods are able to predict the harmful algal blooms?
5. What is the difference between an algal and a cyanobacterial bloom?
6. What are the main toxins involved in the cyanoHABs?

Thank you for your attention!

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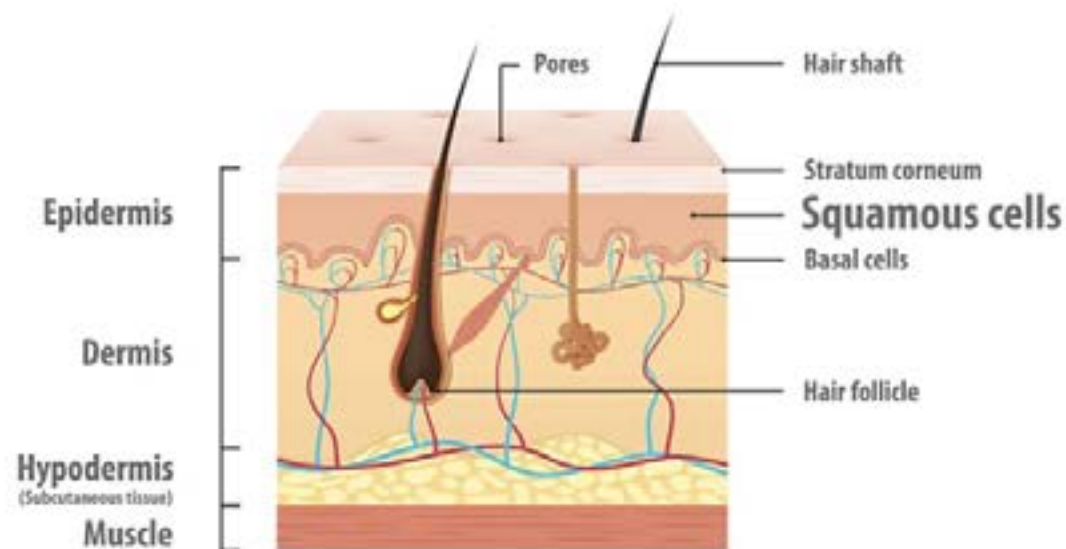
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The Impact of Climate Change on Allergy and Dermal Diseases

1. Introduction

Allergies affect up to 30-40% of the population worldwide, with around 300 million people estimated to suffer from asthma alone. In the EU, avoidable indirect costs per patient insufficiently treated for allergy range between €55 and €151 billion per annum (2014) due to absenteeism and presentism.



Dermal diseases were the 4th leading cause of non-fatal disease burden worldwide (in 2013) and contribute 1.79% of the total global disease burden. In Europe alone, the total annual expenditure associated with adult moderate-to-severe atopic dermatitis is estimated to be €27 billion.

The severity and complexity of these diseases continues to increase due to lifestyle and diet changes, climate change, increased pollution, urbanisation, and reduced biodiversity. As regards climate change effects, increased air pollution and changes in the levels and types of aeroallergens such as pollens, fungi, dust mites,

and animal dander all contribute to these issues.

Climate change is expected to exacerbate the distribution and frequency of dermatologic conditions, particularly those associated with infectious aetiologies, sun exposure,

environmental irritants, and aquatic transmission.

2. Learning Outcomes

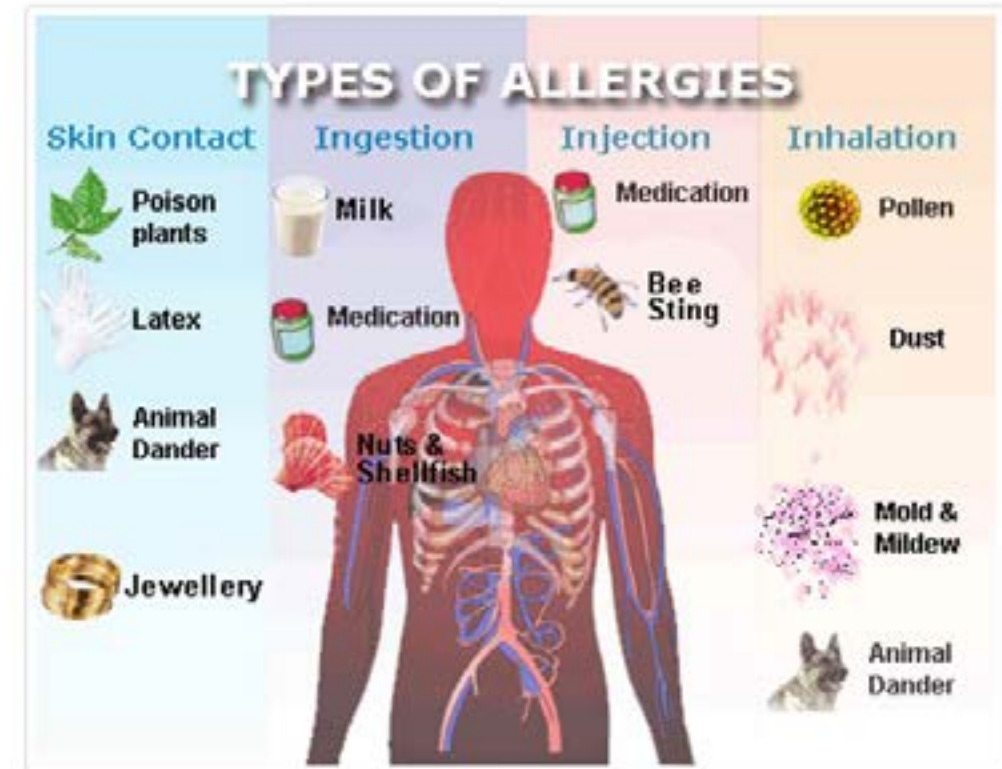
Upon successful completion of the lesson, students will be able to

- ✓ develop an understanding of the allergy and dermal diseases in terms of their pathogens and general clinical features;
- ✓ discuss the environmental and other stressors that influence infectious disease pathogenesis and propagation;
- ✓ assess the effects of recent global change drivers that are pertinent to disease emergence, local-scale dynamics and global spread of these diseases;
- ✓ survey and analyse the current literature to maintain an up-to-date knowledge of allergy and dermal diseases that are aggravated by climate change;
- ✓ critique, for individual diseases of this type, the effects predicted from the latest climate change data and modelling results;
- ✓ understand and evaluate the control methods for the prevention and mitigation of allergy and dermal diseases aggravated by climate change.

3. Overview of Allergy and Dermal Diseases

3.1 General considerations

Allergy diseases are a group of immune-mediated disorders mainly caused by an IgE (immunoglobulin)-dependent immunological reaction to an innocuous environmental antigen (allergen).



Dermal diseases include all conditions that irritate, clog or damage the skin, as well as skin cancer.

According to the site of contact with the allergen, different clinical manifestations may develop in the body. Those predisposed on a genetic basis to synthesize IgE to environmental allergens are atopic (a hypersensitivity reaction such as eczema or asthma may occur in a part of the body not in contact with the allergen).

Allergic diseases result from a complex interplay of immune cells, foreign proteins, and tissue inflammation.

Skin diseases can be genetic in origin and/or can be developed by contagion, pregnancy, stress or hormonal changes, or as a result of a pre-existing health condition such as diabetes, inflammatory bowel disease, or lupus.

3.2 Major allergy diseases

Disease	Causes/triggers	Symptoms/clinical features	Affected by climate change?
Allergy	Genetic predisposition, drug/environmental/food/latex/pet allergens	Runny nose, sneezing, pain/tenderness around cheeks, eyes or forehead, coughing, breathlessness, itchy skin, rash, diarrhoea, nausea/vomiting, swollen eyes, lips, mouth or throat.	Yes
Anaphylaxis	Certain allergens: foods, some medications, insect venom, latex.	Rapid, severe allergic reaction: rapid, weak pulse, skin rash, nausea, vomiting, death.	Yes
Angioedema	Animal dander, exposure to water, sunlight, cold or heat, foods, insect bites, pollen, autoimmune diseases such as lupus.	Swelling below the skin surface, abdominal cramping, breathing difficulty.	Yes
Aspergillosis	<i>Aspergillus</i> fungus	Wheezing, shortness of breath, cough, stuffiness, runny nose, headache.	Yes
Asthma	Dust mites, animal fur, pollen, smoke, exercise viral infections, inhalation of chemical or other allergens.	Coughing, wheezing, chest tightness, breathlessness, death.	Yes
Chronic granulomatous	Genetic predisposition	Fever, chest pain, swollen lymph glands, runny nose, rash, swelling/redness in the mouth, gastrointestinal problems, pneumonia.	No
Chronic rhinosinusitis	Allergens, pre-existing conditions such as cystic fibrosis.	Nasal obstruction, thick nasal discharge, facial pain/pressure, reduction/loss of sense of smell.	Yes
Churg-Strauss syndrome	Thought to be a combination of genetic predisposition and exposure to allergens.	Blood vessel inflammation, nasal allergies, sinus problems, rash, gastrointestinal bleeding, pain and numbness in the hands and feet, adult-onset asthma, death.	Yes
Cold urticaria	Exposure to cold and in some cases genetic predisposition.	Hives, swelling of hands, lips, tongue or throat, anaphylaxis, death.	No
Common variable immunodeficiency (CVID)	Genetic predisposition	Bronchitis, bacterial and viral infections of the upper airway, sinuses, and lungs, pneumonia.	No
Esophagitis	Food/medicine allergens	Difficult/painful swallowing, chest pain, heartburn, acid regurgitation.	Yes
Hay fever (allergic rhinitis)	Pollen	Sneezing, runny/blocked nose, conjunctivitis, itchy throat, mouth, nose and ears, cough.	Yes
Pneumonitis	Aeroallergens, certain drugs.	Shortness of breath, cough, fatigue, loss of appetite, weight loss.	Yes
Urticaria (hives)	Food/medicine allergens, insect venom.	Rash, hives, precursor to angioedema.	Yes

3.3 Major dermal diseases (excluding vector-borne dermal diseases¹)

Disease	Causes/triggers ²	Symptoms/clinical features	Affected by climate change?
Acne	Genetic predisposition, hormonal changes, certain medicines, cosmetics, smoking, high glycaemic diets.	Pimples, skin nodules, cystic lesions.	No
Actinic keratosis	Sun damage	Dry, scaly skin patches, possible precursor to skin cancer.	Yes
Alopecia areata	Genetic predisposition, certain medicines, hormonal changes, stress.	Hair loss	Yes
Cellulitis	Injuries/infections that allow bacteria to penetrate the skin.	Red, swollen, painful skin on feet or legs, fever.	Yes
Chickenpox	Contact or airborne <i>varicella-zoster</i> virus	Rash, fever, headache, pneumonia, encephalitis, sepsis, death.	Yes
Cutaneous larva migrans	Contact with hookworm larvae	Serpiginous skin lesions.	Yes
Cutaneous myiasis	Contact with larvae of the fly order Diptera	Painful larvae-containing ulcers/sores.	Yes
Diphtheria	Contact or airborne <i>corynebacterium diphtheriae</i> bacteria	Fever, respiratory system attack, skin sores/ulcers, myocarditis, nerve damage, kidney failure, death	Yes
Eczema (atopic/contact dermatitis)	Genetic predisposition, environmental allergens, chemicals.	Red, dry skin patches, rash, skin thickening, conjunctivitis.	Yes
Epidermolysis bullosa	Genetic predisposition	Skin fragility, tears, sores, blisters on skin.	No
Herpes simplex	Contact or bodily fluid <i>herpes simplex</i> virus.	Pain, itching and sores around the genitals, anus or mouth.	Yes
Gonorrhea	Contact <i>neisseria gonorrhoeae</i> bacterium	Fever, rash, skin sores, joint pain, swelling and stiffness.	Yes
Hand-foot-and-mouth disease	Contact or airborne <i>Coxsackievirus</i> .	Fever, sore throat, nausea, painful mouth lesions, rash.	Yes
Hidradenitis suppurativa	Hormonal changes, smoking, obesity.	Painful abscesses, scarring of the skin.	No
Ichthyosis	Genetic predisposition	Dry, scaly, itchy, red skin.	No
Impetigo	Contact <i>staphylococci</i> bacteria	Red sores on face.	Yes
Marburg	Contact <i>marburg</i> virus	Fever, headache, rash, vomiting, diarrhoea, jaundice, haemorrhaging, multi-organ failure, death.	Yes
Measles	Contact or airborne <i>measles morbillivirus</i> .	Fever, cough, conjunctivitis, Koplik spots, rash, pneumonia, encephalitis, death.	Yes
Monkeypox	Contact <i>mpox</i> virus	Rash, scabs, fever, headache, swollen lymph nodes, respiratory symptoms.	Yes

¹ Dealt with in the lesson on "Effect of Climate Change on Vector-Born and Related Diseases"

² Here "contact" means physical contact with solids or fluids containing the pathogen

Major dermal diseases (contd.)

Disease	Causes/triggers	Symptoms/clinical features	Affected by climate change?
Prurigo nodularis	Not known. Among risk factors is atopic dermatitis.	Itchy skin nodules on arms, legs, abdomen, and/or back.	Possibly
Psoriasis	Genetic predisposition, skin injury, throat infections, certain medicines.	Flaking skin patches/scales	Yes
Reynaud's disease	Cold temperatures	Cold, numb, white/blue skin on fingers or toes	No
Ringworm (tinea corporis)	Contact <i>trichophyton</i> , <i>microsporum</i> , or <i>epidermophyton</i> fungi.	Itchy, red, circular rash.	Yes
Rosacea	Genetic predisposition, certain chemicals in food, alcohol, climatic conditions.	Red spots/rash on the face.	Yes
Rubella	Airborne or contact <i>rubella</i> virus	Red rash, red eyes, fever, headache, cough, arthritis (in women), miscarriage, birth defects and death (in newborn children)	Yes
Shingles	<i>Varicella-zoster</i> virus pre-acquired from chickenpox	Painful rash on one side of face or body.	Yes
Skin cancers (basal cell, squamous cell, melanoma)	Genetic predisposition, exposure to the sun, kidney dialysis, arsenic ingestion.	Lesions or lumps on the skin, in the case of squamous cell and melanoma: metastasis, death.	Yes
Scabies	Contact human itch mite (<i>sarcoptes scabiei</i> var. <i>hominis</i>)	Itchy, pimple-like rash.	Yes
Syphilis	Contact <i>treponema pallidum</i> bacterium	Single chancre (sore), rashes, lesions, fever, swollen lymph nodes, attack of vital organs, death.	Yes
<i>Vibrio vulnificus</i>	Open wound contact with fluids or ingestion of seafood containing <i>vibrio vulnificus</i> bacteria	Blistering skin lesions, fever, vomiting, diarrhoea, necrotizing fasciitis, death.	Yes
Viral warts	Contact <i>human papilloma</i> virus	Warts.	Yes
Vitiligo	Genetic predisposition, sunburn, injured skin, certain chemicals.	Symmetrical loss of skin pigment/colour on both sides of the body.	Yes

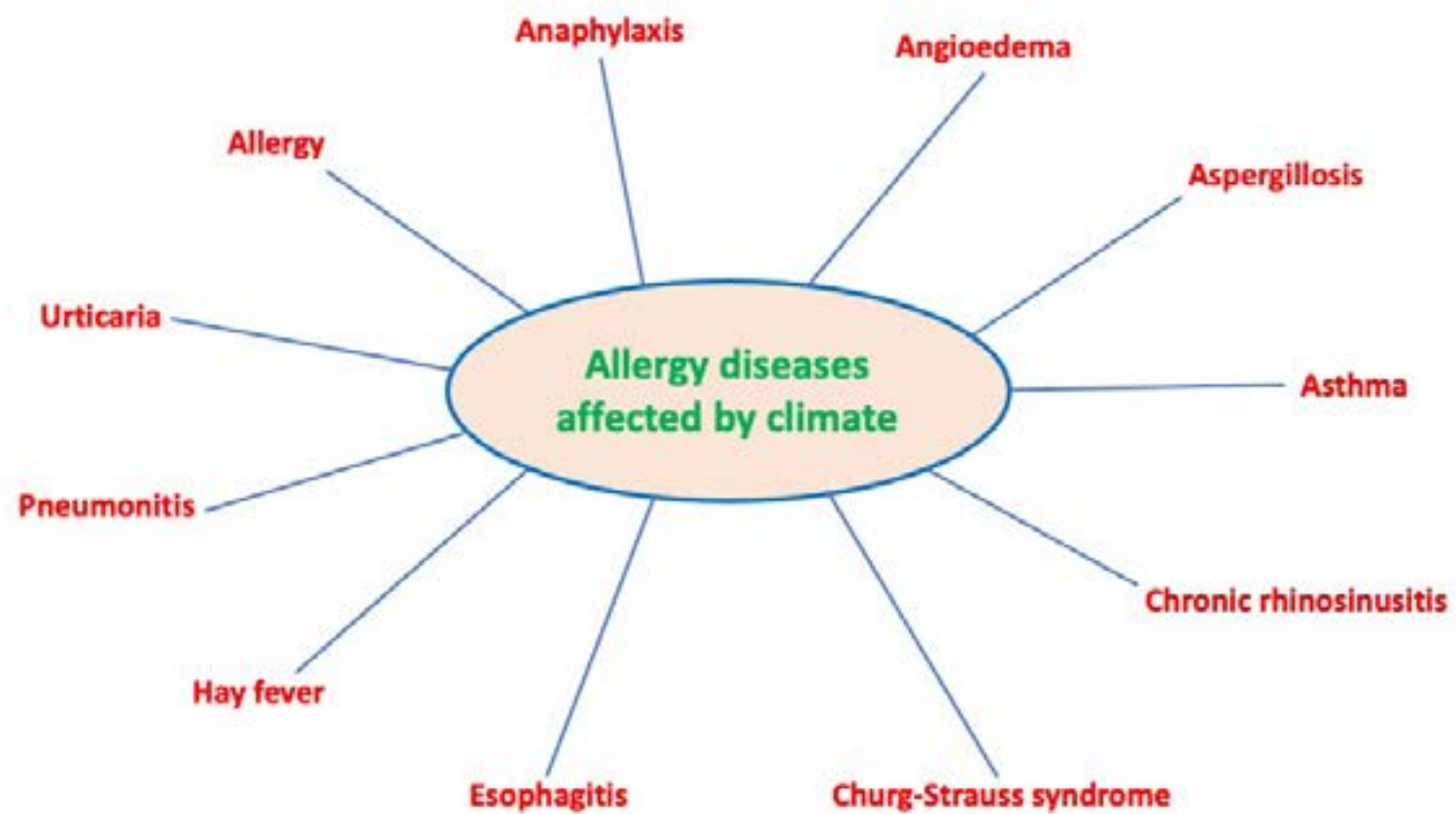


Figure 1. Allergy diseases affected by climate

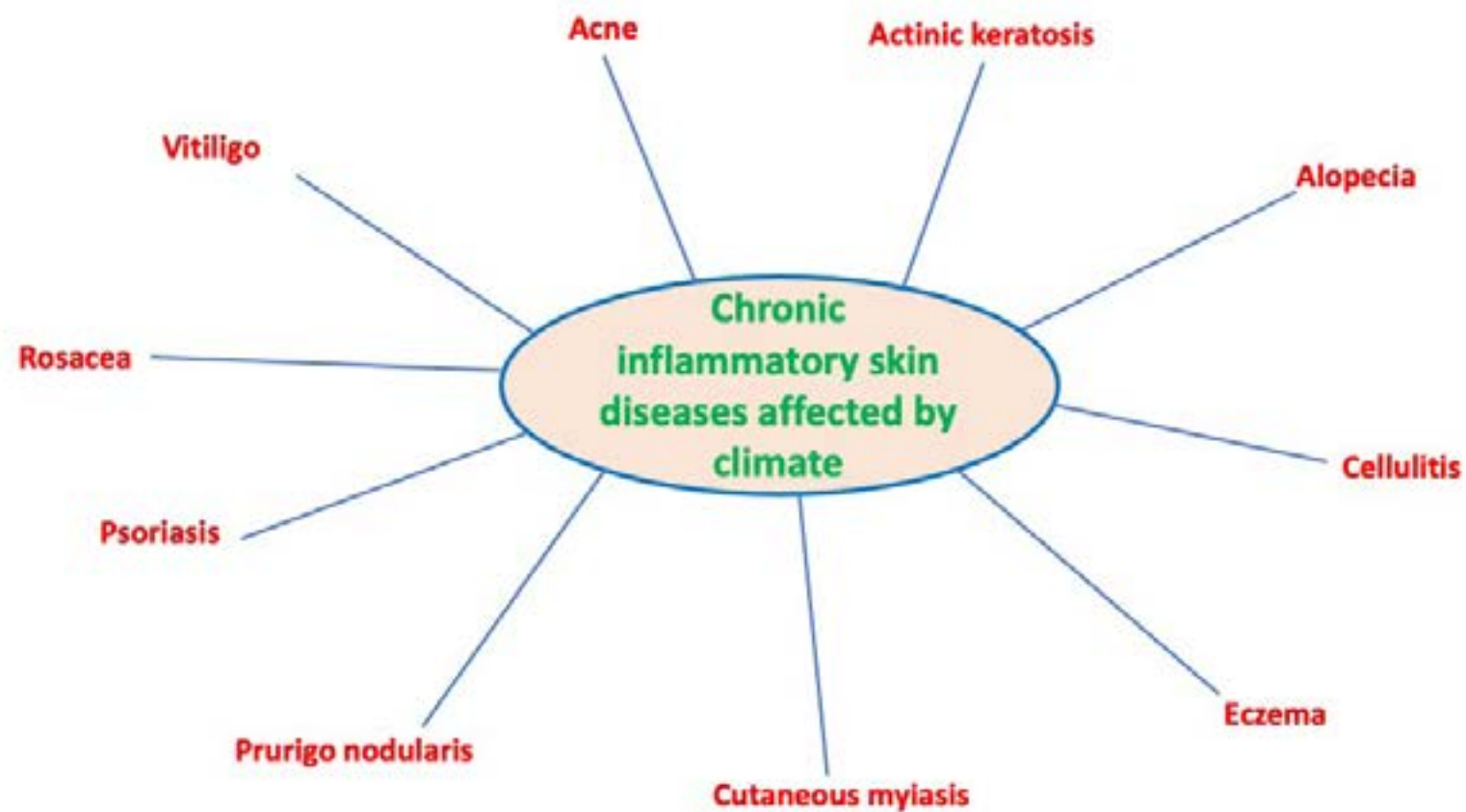


Figure 2. Chronic inflammatory dermal diseases affected by climate

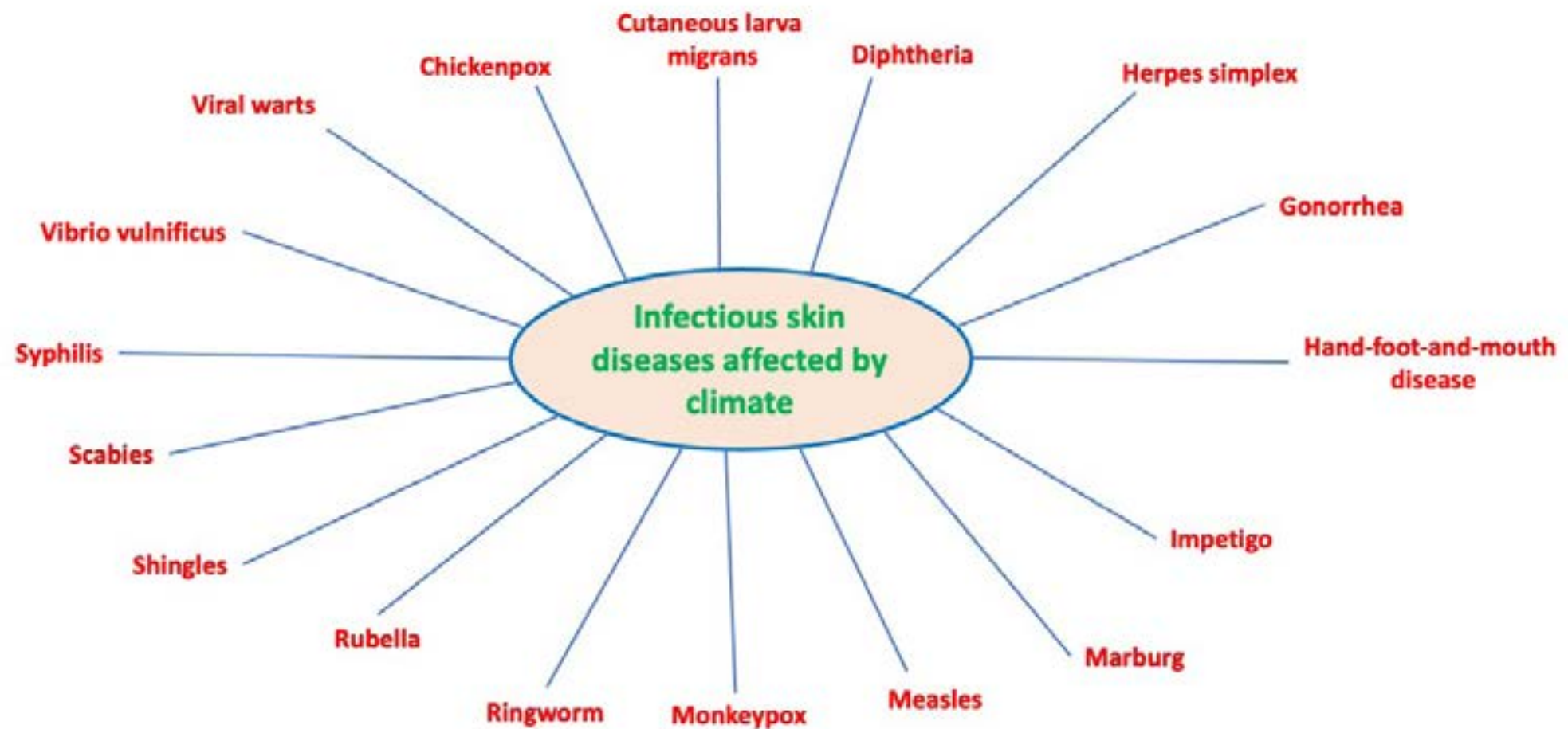


Figure 3. Infectious dermal diseases affected by climate

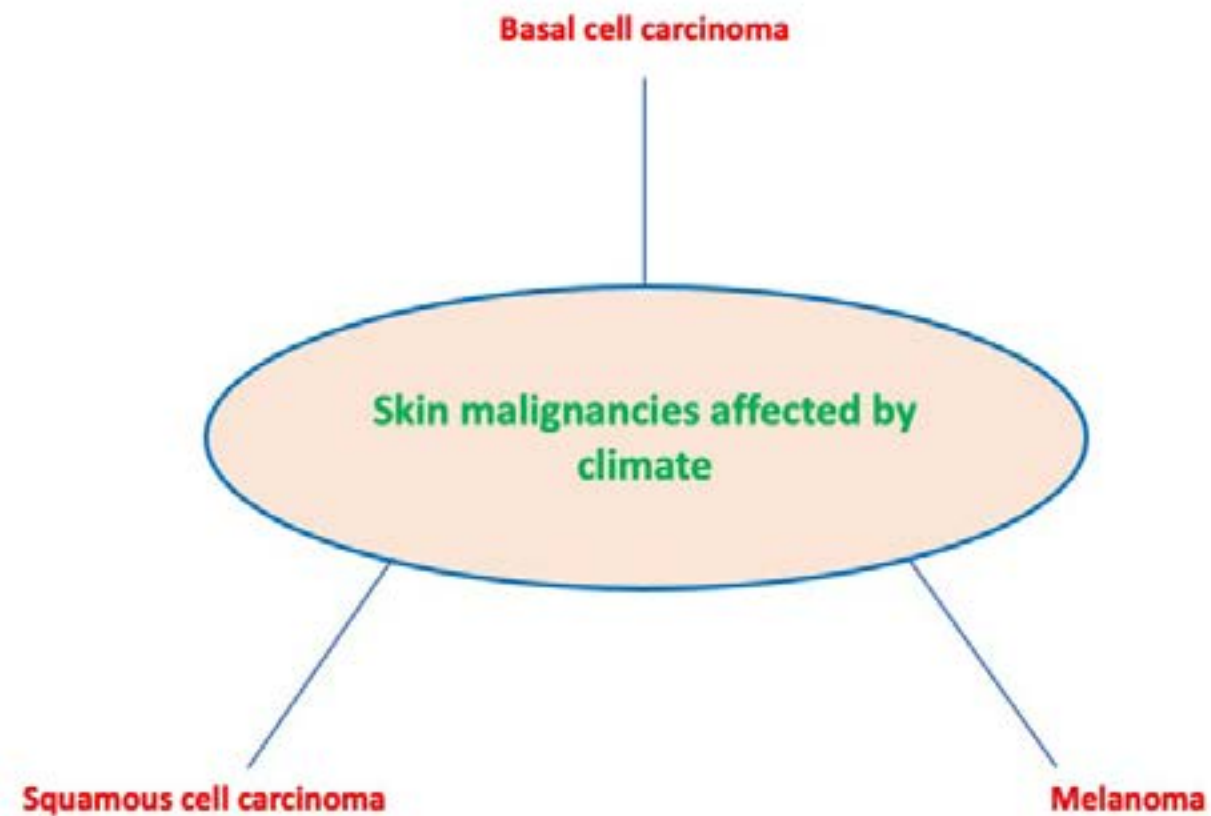


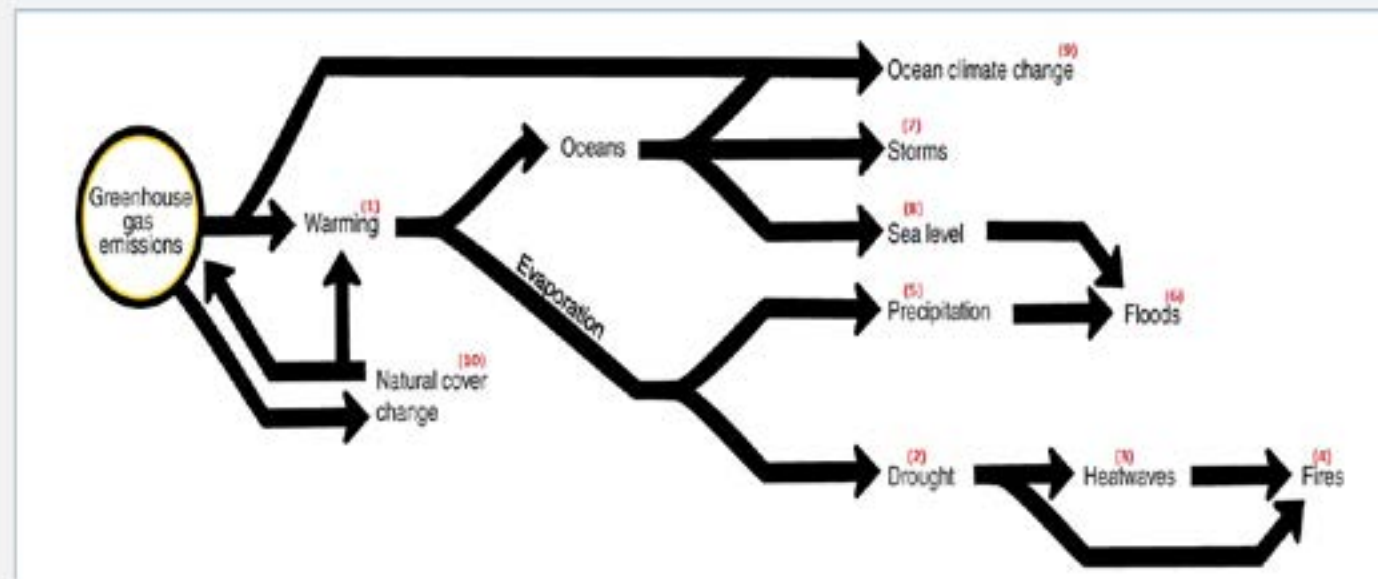
Figure 4. Skin malignancies affected by climate

3.4 Summary

It is obvious from the above sections that most (89%, 41/46) allergy and dermal diseases are affected by climate in various ways and for a number of reasons. Notable exceptions are those diseases that have causes/triggers associated solely with genetic predisposition,

hormonal changes, lifestyle choices, or animal hair/fur/dander. We can group all of these diseases into to four general categories: allergy; chronic inflammatory dermal; infectious dermal; and malignancies.

Figure 3. Climatic hazards of the Earth's system affected by the ongoing emission of Greenhouse Gases (GHGs).



From: C. Mora et al., Nature Climate Change, September 2022, 12, 869–875, <https://doi.org/10.1038/s41558-022-01426-1>

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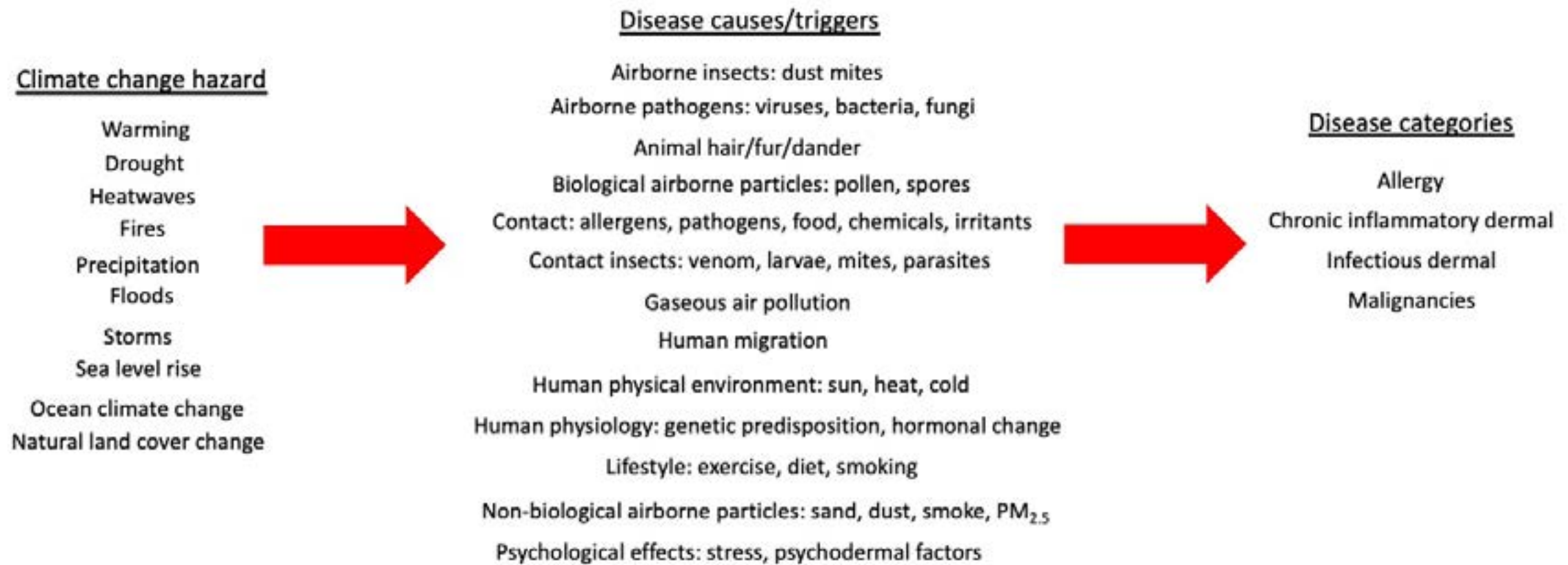
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GHGs mediate the balance between incoming solar radiation and outgoing infrared radiation; thus, **(1)** their excess in the atmosphere causes warming. Compounded with an increased capacity of the air to hold water, warming accelerates soil water evaporation, leading to **(2)** drought in places that are commonly dry; excess drought can lead to **(3)** heatwaves. These ripen the conditions for **(4)** wildfires. In moist places, the quick replenishment of evaporation strengthens **(5)** precipitation, causing **(6)** floods. Warming of the oceans enhances evaporation and wind speeds, intensifying the strength of **(7)** storms, whose surges can be aggravated by **(8)** sea level rise. Uptake of CO₂ in the oceans causes ocean acidification, whereas changes in ocean circulation and warming reduces oxygen concentration in

seawater, leading to **(9)** ocean climate change. Change in natural land cover **(10)** can be a direct emitter of GHGs via deforestation and respiration, temperature modification via albedo* and evapotranspiration, and because it can be a direct modifier in the transmission of pathogenic diseases.

*The fraction of light that the earth's surface reflects back into space.

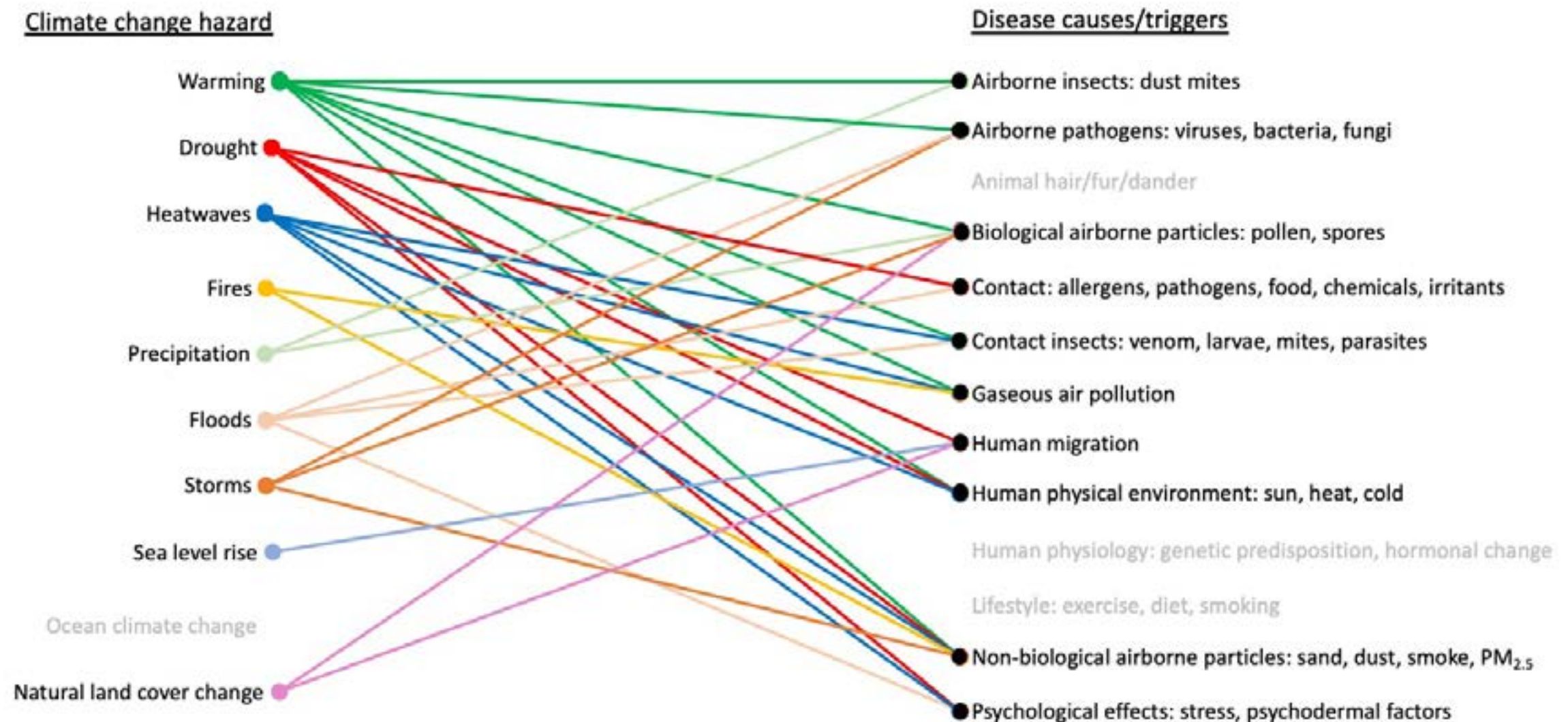
4.2 Links between stressors and disease causes/triggers



From the previous sections we can see that there are more than 40 allergy and dermal diseases that can be affected by one or more of 10 climate change stressors via many different disease causes or triggers. We can get an overall view of these inter-relationships for each of the four disease categories by considering

the causal links between the climate change stressors and a generalised list of disease causes/triggers:

Figure 6. Allergy diseases: Causal relationships between climate change hazards and disease causes/triggers*



*Items in grey are not climate-related hazards/causes/triggers for this disease type

Figure 7. Chronic inflammatory dermal diseases: Causal relationships between climate change hazards and disease causes/triggers*

Climate change hazard

Warming
Drought
Heatwaves
Fires
Precipitation
Floods
Storms
Sea level rise

Ocean climate change

Natural land cover change

Disease causes/triggers

Airborne insects: dust mites
Airborne pathogens: viruses, bacteria, fungi
Animal hair/fur/dander
Biological airborne particles: pollen, spores
● Contact: allergens, pathogens, food, chemicals, irritants
● Contact insects: venom, larvae, mites, parasites
● Gaseous air pollution
● Human migration
● Human physical environment: sun, heat, cold
Human physiology: genetic predisposition, hormonal change
Lifestyle: exercise, diet, smoking
● Non-biological airborne particles: sand, dust, smoke, PM_{2.5}
● Psychological effects: stress, psychodermal factors

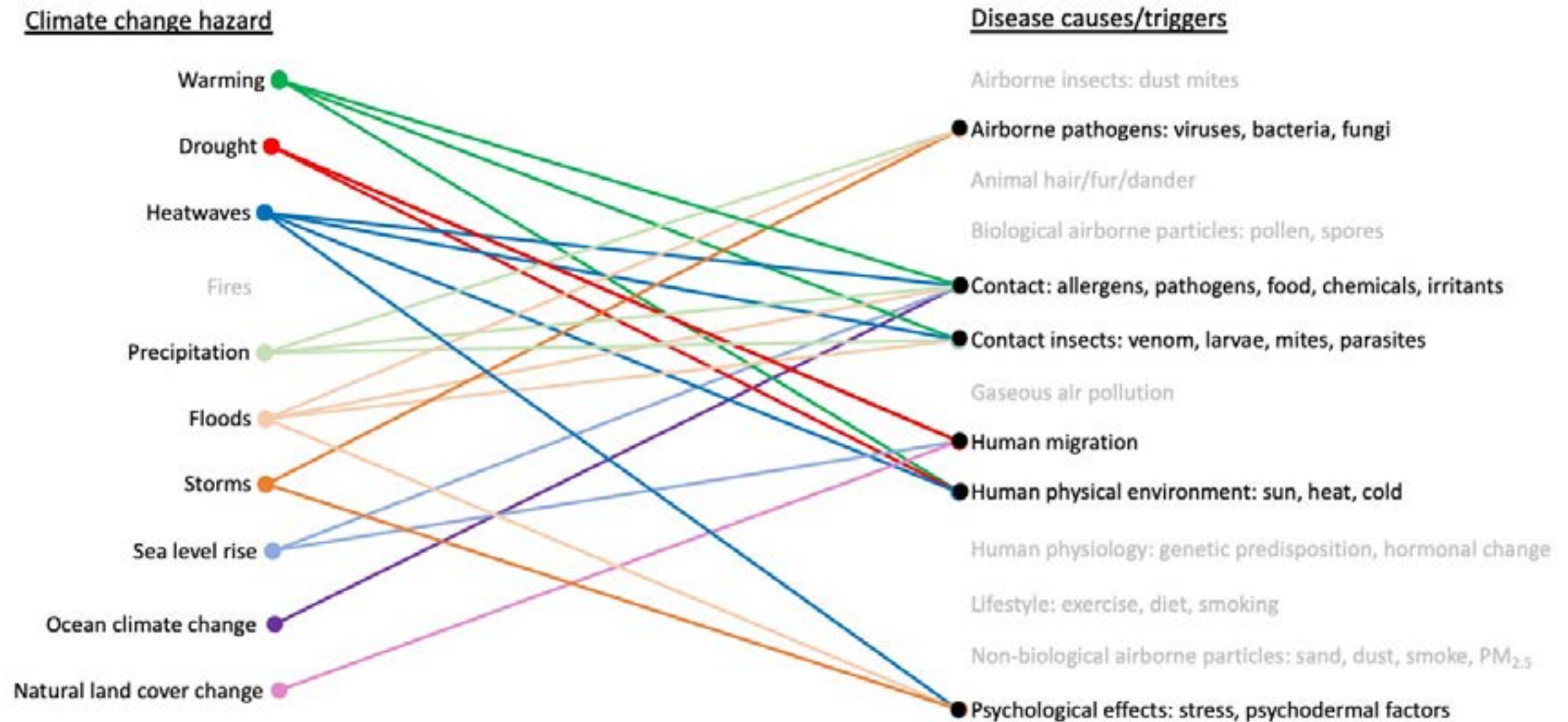
*Items in grey are not climate-related hazards/causes/triggers for this disease type

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Figure 8. *Infectious skin diseases: Causal relationships between climate change hazards and disease causes/triggers**



*Items in grey are not climate-related hazards/causes/triggers for this disease type

Figure 9. *Skin malignancies: Causal relationships between climate change hazards and disease causes/triggers**

Climate change hazard

Warming

Drought

Heatwaves

Fires

Precipitation

Floods

Storms

Sea level rise

Ocean climate change

Natural land cover change

Disease causes/triggers

Airborne insects: dust mites

Airborne pathogens: viruses, bacteria, fungi

Animal hair/fur/dander

Biological airborne particles: pollen, spores

● Contact: allergens, pathogens, food, chemicals, irritants

Contact insects: venom, larvae, mites, parasites

● Gaseous air pollution

Human migration

● Human physical environment: sun, heat, cold

Human physiology: genetic predisposition, hormonal change

Lifestyle: exercise, diet, smoking

Non-biological airborne particles: sand, dust, smoke, PM_{2.5}

Psychological effects: stress, psychodermal factors

*Items in grey are not climate-related hazards/causes/triggers for this disease type

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5. Current state of knowledge on effects of climate change on allergy and dermal diseases

5.1 Allergy diseases

May 2023: Unprecedented wildfires in Alberta, Canada and Extremadura, Spain, cause increased air pollution over vast areas.





May 2023: Emilia-Romagna region suffers Italy's worst floods in 100 years.



In the case of allergy diseases caused/triggered by **air pollution**, figure 10 shows the inter-relationships between climate change, air pollution, the allergens/triggers, and the human body, and table 1 indicates the health outcomes from these climate change effects.

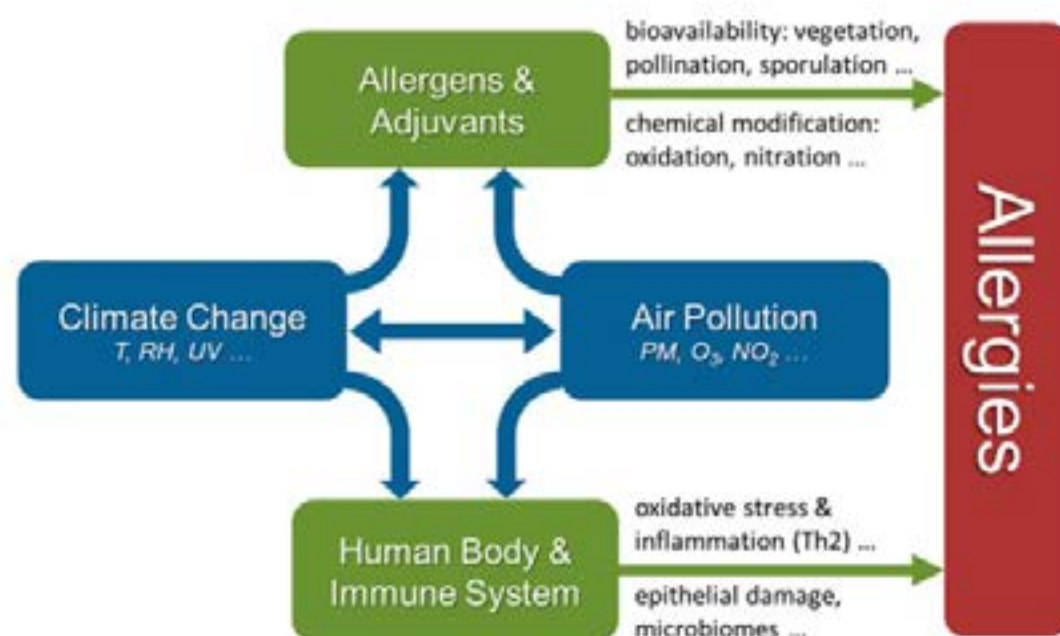


Figure 10. Interplay of air pollution and climate change in the promotion of allergies

From: K. Reinmuth-Selzle et al., Environ. Sci. Technol., 51, 2017, 4119–4141.
DOI: <http://dx.doi.org/10.1021/acs.est.6b04908>

Environmental changes	Health outcomes
More frequent extreme climate events	
Heatwaves, wildfires, higher temperatures, etc	Amplification of exacerbation rate, morbidity, and mortality of respiratory diseases.
Intensive rain and flooding	Dampness in affected households with subsequent proliferation of molds and cockroaches.
Thunderstorms	Increase in asthma exacerbations and hospitalizations following thunderstorm-related asthma episodes
More intense and more prolonged pollen seasons. Possibly similar changes for other allergens (e.g., fungi).	Increase in the severity and alteration of the seasonality of symptoms of allergic rhinitis and asthma
Alteration of the local vegetation patterns with changes in the geographical spread and migration of plants. Colonization of geographical areas by new species with alteration of the species dominating distinct ecological niches.	Increased prevalence and severity of allergic rhinitis and asthma due to both de novo sensitizations and cross-reactivity with pre-existing species
Possibly, similar changes for fungi.	
Possibly changes in the growth pattern and distribution of pathogenic microorganisms.	Possibly changes in the pattern of respiratory tract infections

Table 1. Allergy-related health outcomes arising from climate change events

From: I. Eguluz-Gracia et al., Allergy, 2020, 75, 2170–2184. DOI: <https://doi.org/10.1111/all.14177>

Predicted Eastern U.S.A. tree habitat distributions for both low and high GHG emissions scenarios in 2100 (figure 11) show the potential for large increases in **allergenic tree pollen** levels in many states. Figure 12 shows similar effects for ragweed pollen.

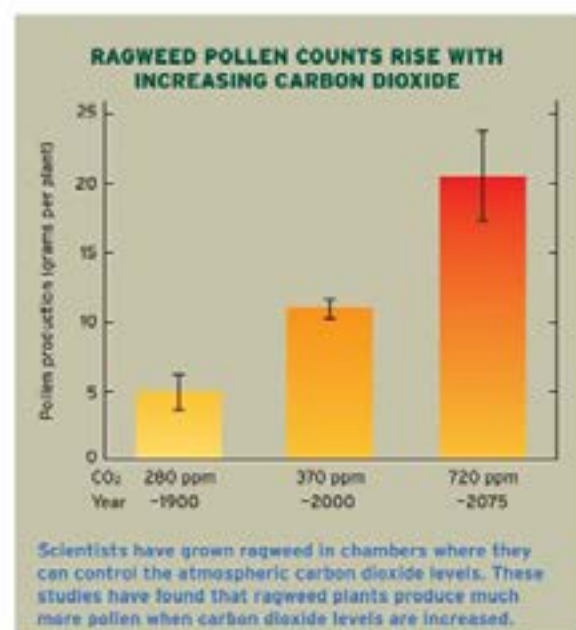


Figure 12. Increase in ragweed pollen with increasing CO₂ levels.

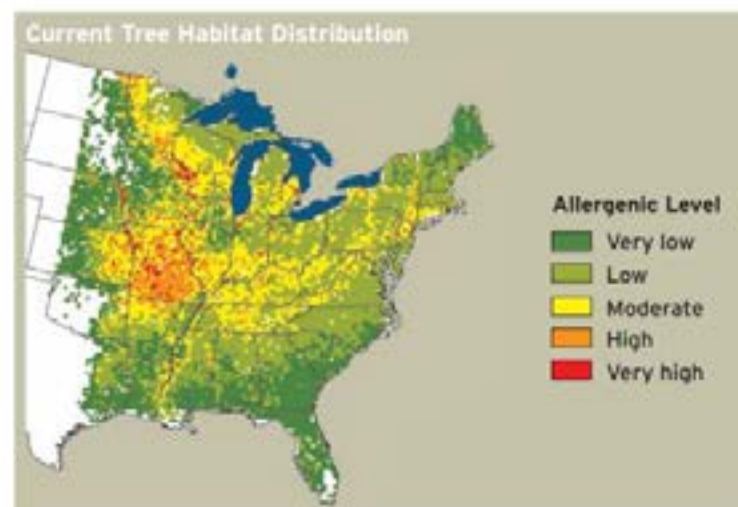
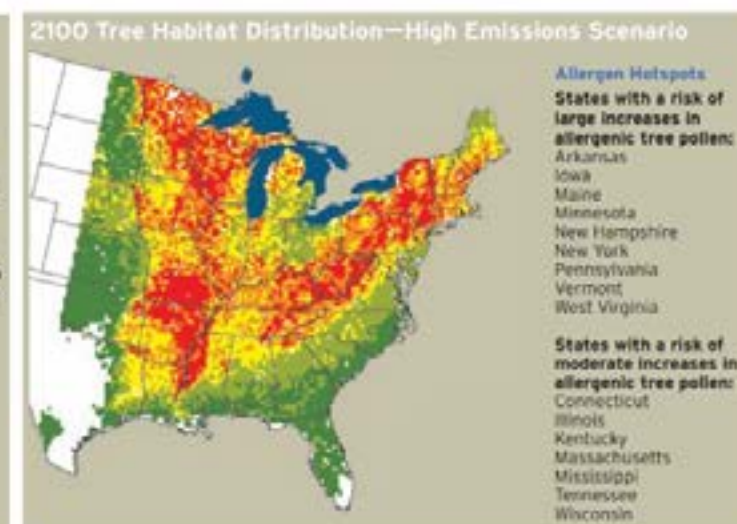
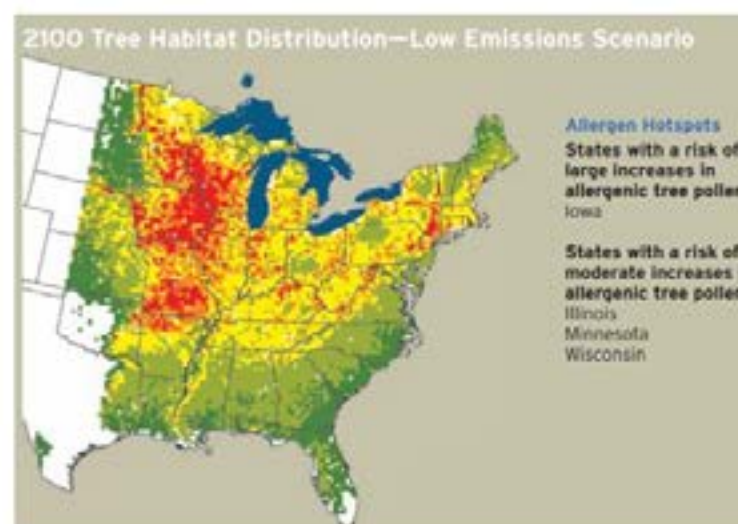


Figure 11. Current and predicted tree habitat distributions for the Eastern U.S.A. for both low and high greenhouse gas emission scenarios.



From: "Extreme Allergies and Global Warming Report", 2010, National Wildlife Federation and Asthma and Allergy Foundation of America. <https://aafa.org/asthma-allergy-research/our-research/climate-health/>. Accessed on 11th June 2023.

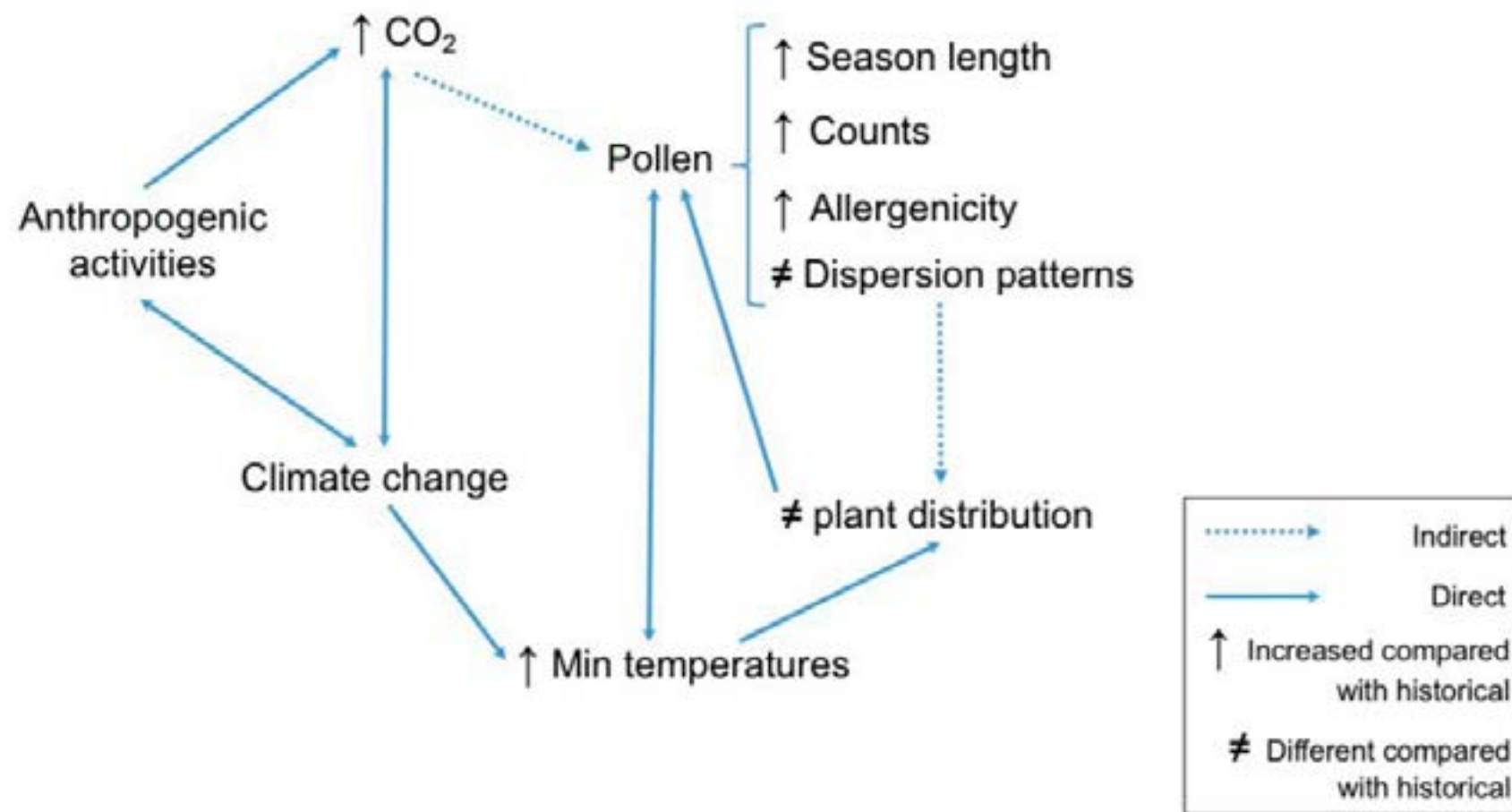


Figure 13. Effects of climate change on aeroallergens.

From: C. Sierra-Heredia et al., Int. J. Environ. Res. Public Health, 2018, 15, 1577. <https://doi.org/10.3390/ijerph15081577>

An interesting synergy has been observed between **thunderstorm** activity and pollen levels in reported asthma cases in various countries (table 2)

Characteristics of the described epidemics of asthma associated with thunderstorms

1. The occurrence of epidemics is closely linked to thunderstorms.
2. Epidemics related to thunderstorms are limited in late spring and summer when there are high levels of pollen grains in the air.
3. There is a close seasonal association between the arrival of the storm, a significant increase in the concentration of pollen grains, and the onset of epidemics.
4. Patients with pollen allergy, who remain intramural with closed windows during thunderstorms, are not involved.
5. There is a great risk for patients who do not have a treatment for optimal asthma. Patients with allergic rhinitis induced by pollen and without a history of asthma may experience bronchoconstriction, which is also sometimes severe.

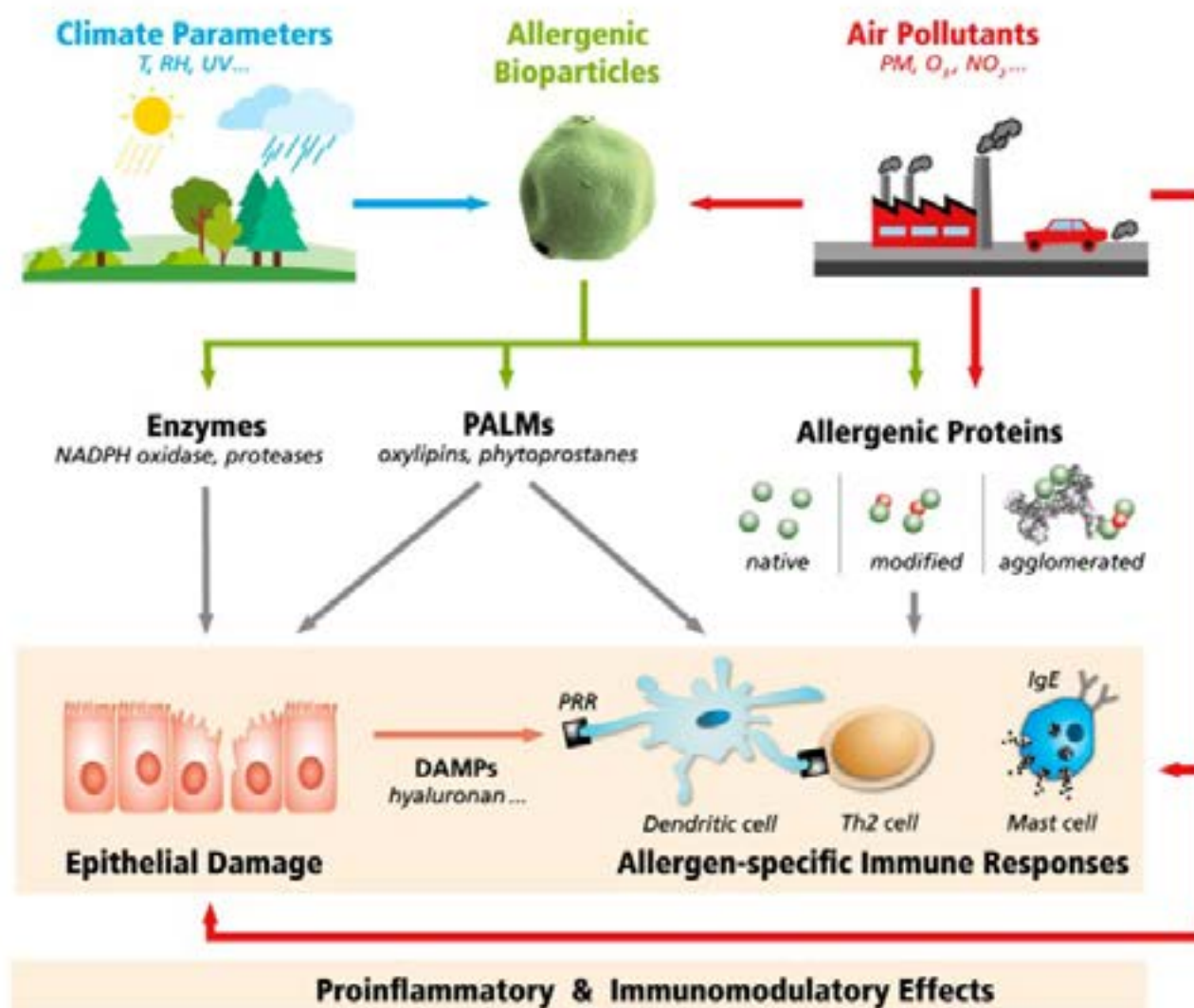
Table 2. Storm associated asthma exacerbations around the world.

Year	Country	Observations
1983	United Kingdom (Birmingham)	26 unexpected cases of asthma crisis related to electrical storms.
1992	Australia (Melbourne)	Storms in late spring in Melbourne can trigger epidemics of asthma attacks (5 to 10 time-increase).
1994	United Kingdom (London)	Visits to the hospital for asthma or other diseases of the respiratory tract. 640 cases attended during a 30-h period in June 1994, almost 10 times the expected number.
1992-2000	Canada	18 970 hospital visits for asthma in children and young people between 2 and 15 y of age.
1993-2004	USA	215 832 consultations for asthma in the Emergency Department (ED); 24 350 of these visits occurred on days following thunderstorms. Significant association between daily counts of asthma ED visits and thunderstorm occurrence. Asthma visits were 3% higher on days following thunderstorms.
2010	Italy (Barietta-Puglia)	20 cases of asthma related to an electrical storm which were due to pollen (olive).
2010	Australia	"Storm asthma" epidemics that occurred in Melbourne during the spring of 2010. The approach of spring, along with the high rainfall in the winter in Melbourne and its surroundings announcing an intense pollen season, increases the risk of rhinitis allergic and asthma in people sensitive to pollen.
2016	Australia (Melbourne)	On Monday, November 21, 2016, associated with severe storms, hospitals were filled with patients with severe asthma attacks. There were more than 9000 subjects with severe and near fatal asthma attacks who needed to go to various emergency departments of the city of Melbourne and 10 died. There were thousands of calls to firefighters and police, as well as doctors and mid-level providers contacted by patients. As in previous epidemics, including the Naples event, many people had no history of asthma, only hay fever.

From: G. D'Amato *et al.*, *Allergy*, 2020, **75**, 2219–2228. <https://doi.org/10.1111/all.14476>

Some additional detail on the specifics of how these effects operate within the human body:

Figure 14. Pathways through which climate parameters and air pollutants can influence the release, potency, and effects of allergens and adjuvants: temperature (T), relative humidity (RH), ultraviolet (UV) radiation, particulate matter (PM), ozone and nitrogen oxides (O₃, NO_x), reduced nicotinamide adenine dinucleotide phosphate (NADPH) oxidase, pollen-associated lipid mediators (PALMs), damage-associated molecular patterns (DAMPs), pattern recognition receptors (PRR), type 2 T helper (Th2) cells, immunoglobulin E (IgE), allergenic proteins (green dots), and chemical modifications (red dots).



From: K. Reinmuth-Selzle et al., Environ. Sci. Technol., 2017, 51, 4119–4141.
DOI: <http://dx.doi.org/10.1021/acs.est.6b04908>

Figure 15 shows the involvement of climate change-induced increases in temperature and humidity as factors affecting increased **dust mite allergy**:

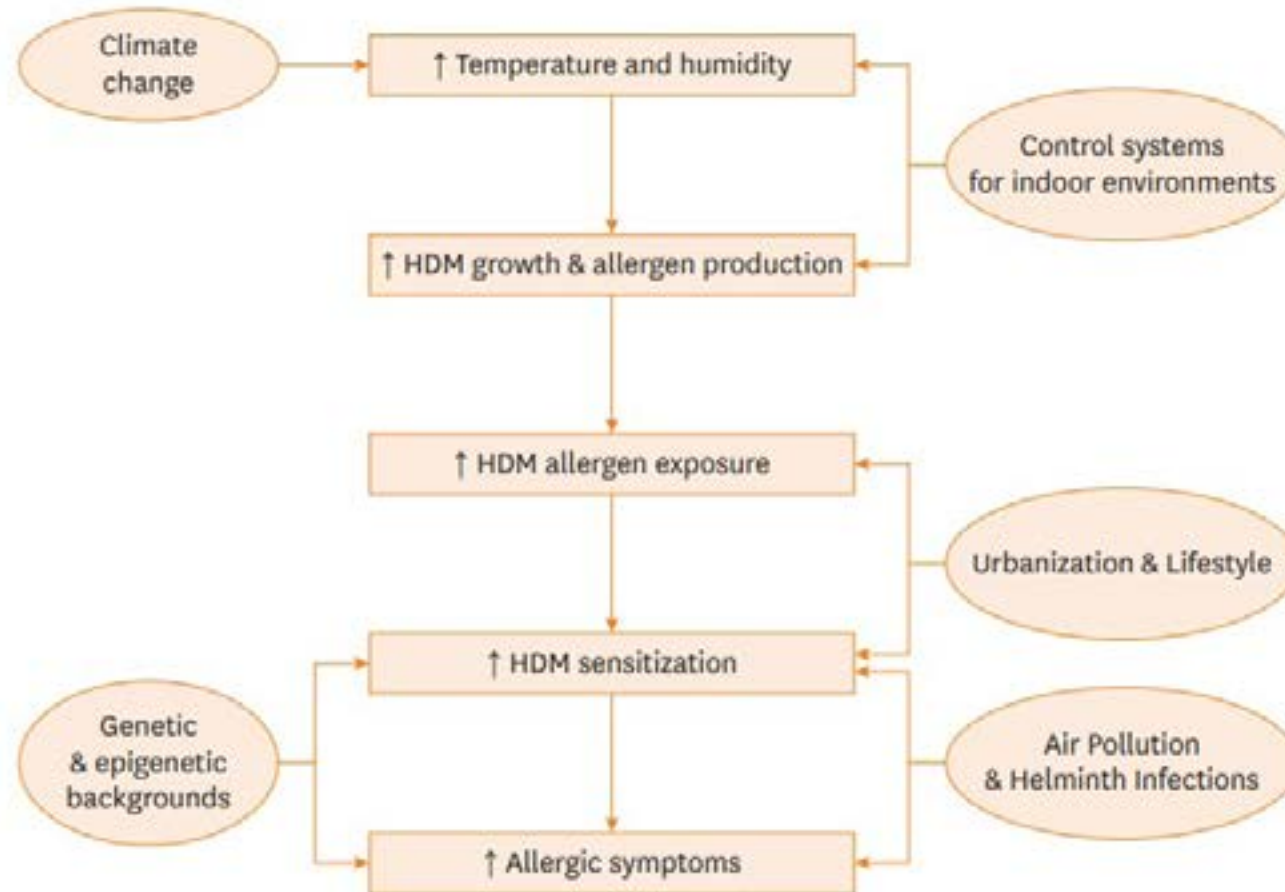


Figure 15. A generalised and simplistic view of multiple factors that could affect house dust mite (HDM) growth, allergen exposure, sensitization and allergic symptoms.

From: N. Acevedo et al., Allergy Asthma Immunol Res., 2019 Jul, **11**, (4), 450-469.
<https://doi.org/10.4168/aair.2019.11.4.450>

The effect of climate change on aspergillosis allergy associated with **airborne aspergillus niger bacteria** can be envisaged in the predicted range changes in habitat suitability for the bacterium (figure 16).

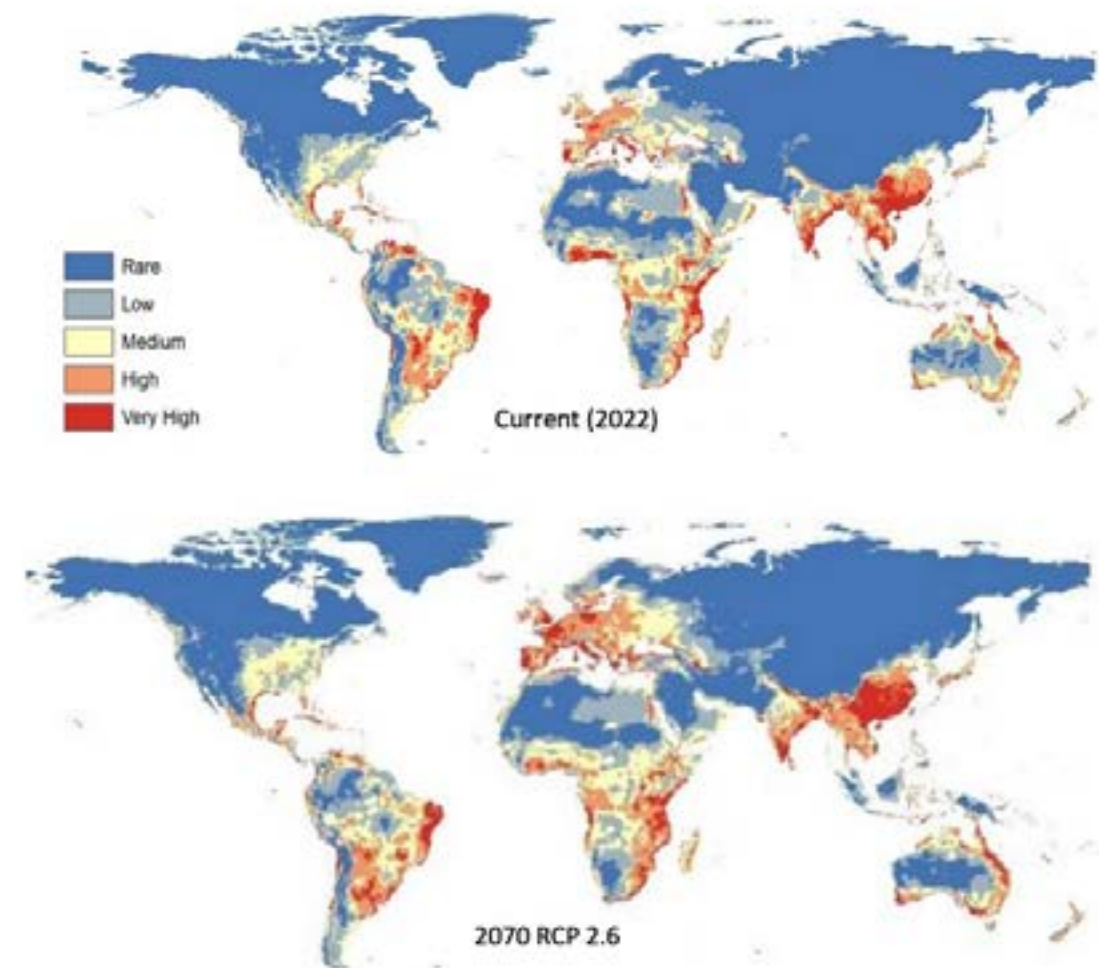


Figure 16. Current and predicted future habitat suitability for the *aspergillus niger* bacterium.

From: M. Alkhalifah et al., Diversity, 2022, 14, 845. <https://doi.org/10.3390/D14100845>

Under the relatively low emission, high greenhouse gas mitigation scenario (RCP 2.6), by 2070 significant range changes are predicted away from tropical regions and into regions currently more temperate, but by 2070 will be warmer and more habitable for this bacterium. In particular, it can be seen that

Europe is predicted to be dramatically and adversely affected in this way.

5.2 Chronic inflammatory dermal diseases

The skin - a simple structural view:

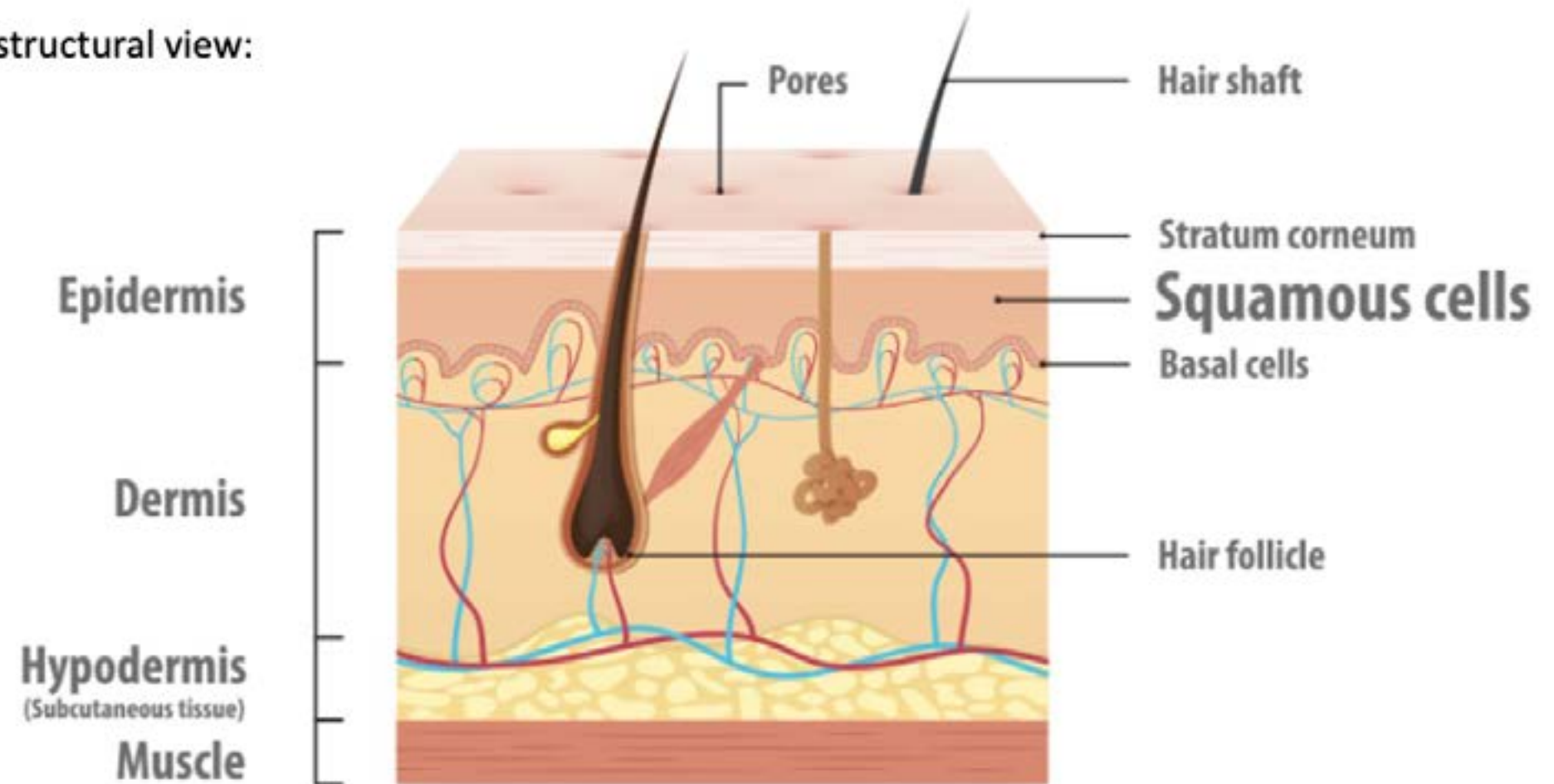
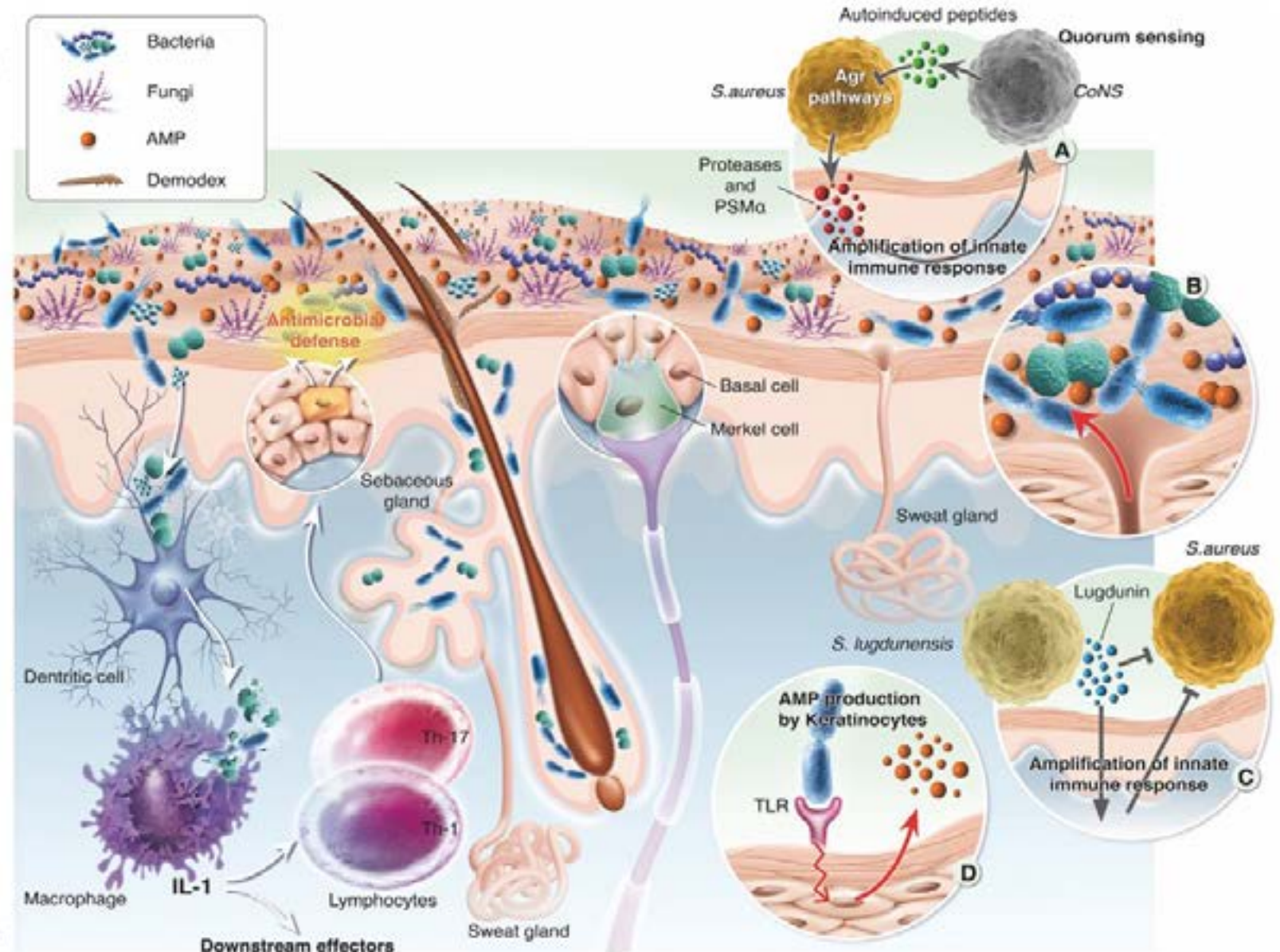


Figure 17. A simple structural view of the human skin

The skin – the dermal microbiome



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Skin microbiota, its roles, and its relationship with the immune system. The skin microbiota is composed of bacteria, fungi, archaea, viruses, and mites (Demodex) that are related to the immune system through dialog with resident dendritic cells resulting from complement activation. **A:** The immune system is enhanced

by the quorum-sensing process between bacterial populations, which can limit the overgrowth of potential pathogens, or by the production of certain antibiotics, such as lugdunin (**C**). Microbiotic homeostasis is dependent on the production of antimicrobial peptides (AMPs) both by bacteria themselves

and by host cells, such as keratinocytes and sebocytes (**B** and **D**).

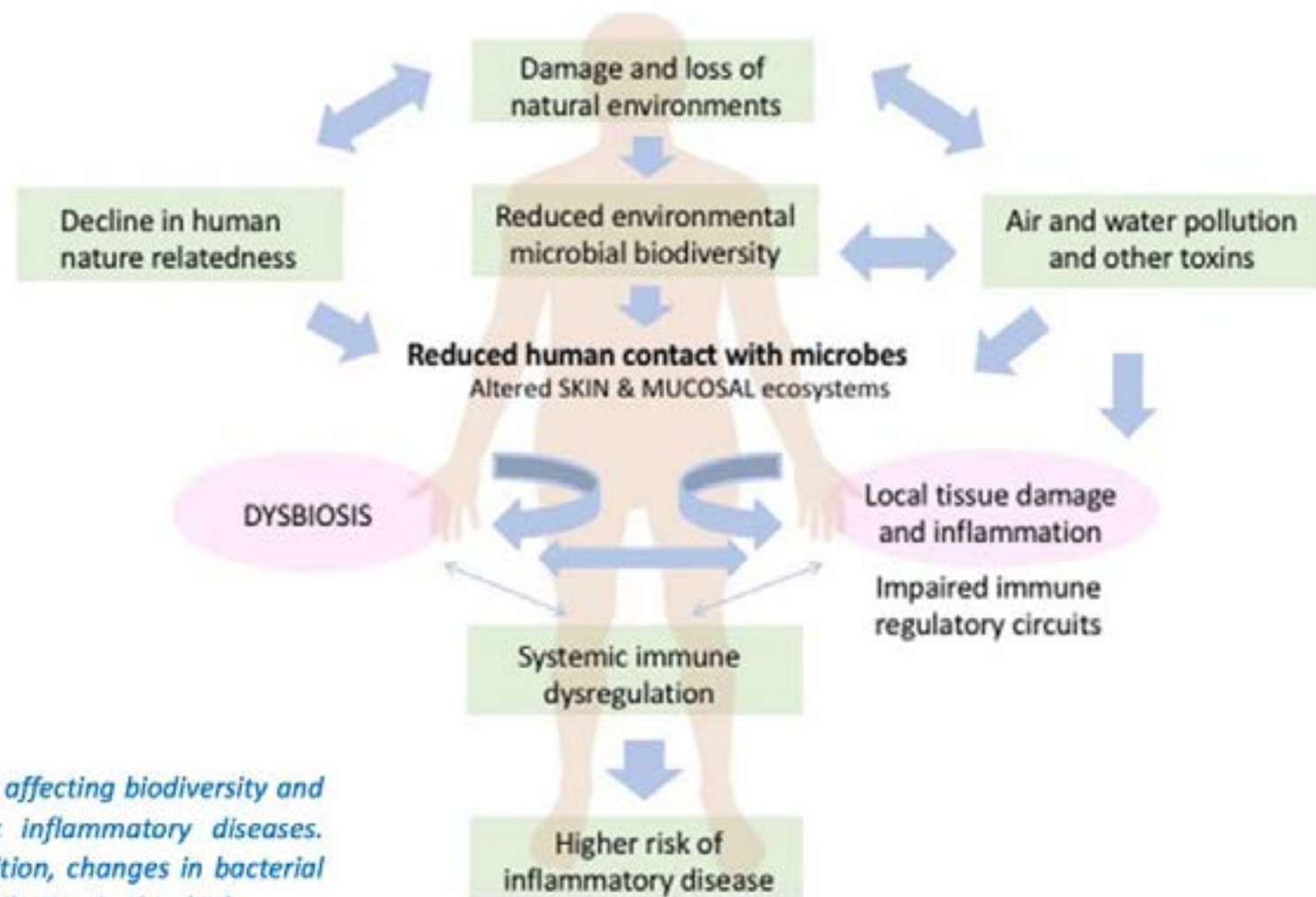
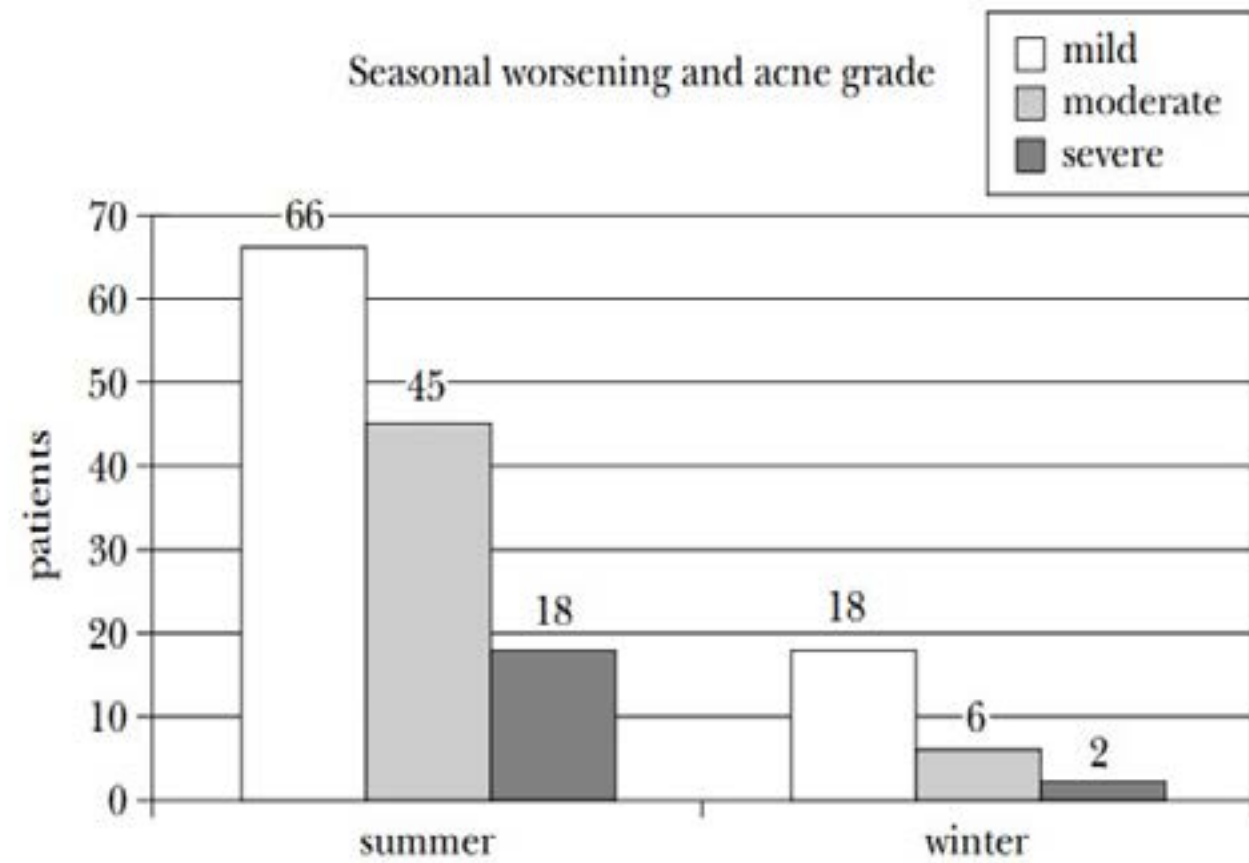


Figure 19. Erosion of environmental ecosystems affecting biodiversity and microbial ecology: a risk factor for chronic inflammatory diseases. (Dysbiosis = an imbalance in bacterial composition, changes in bacterial metabolic activities, or changes in bacterial distribution in the skin).

From: S.L. Prescott *et al.*, World Allergy Organization Journal 2017, **10**, article 29.
<https://doi.org/10.1186/s40413-017-0160-5>

“Erosion of environmental ecosystems is affecting biodiversity and microbial ecology. Together with declining nature-relatedness this is reducing human contact with immunomodulatory organisms found in natural environments – reflected in differences in skin

microbes. This is increasingly being recognised as a risk factor for chronic inflammatory disease”



In the case of **acne**, the effects of climatic variables such as temperature changes have been shown to correlate with acne flares as indicated in figure 20.

Figure 20. Seasonal variation of various grades of acne

From: K. Sardana et al., The Journal of Dermatology, 2002, 29, 484–488.
<https://doi.org/10.1111/j.1346-8138.2002.tb00313.x>

Warmer temperatures have been shown to increase sebum levels, humidity induces swelling of the pilosebaceous unit, and UV radiation causes hyperplasia of sebaceous glands, all of which promotes cutibacterium acnes growth, leading to the development of acne lesions.

Thus it might be expected that increased temperature, humidity and UV exposure as a result of global warming-induced climate change will exacerbate this disease both in terms of occurrence and severity.

Atopic dermatitis (AD, eczema) has been found to result from both genetic predisposition (up to 60% of patients show a deficiency in the filament aggregating protein caused by mutations in the encoding filaggrin gene) and environmental factors.

Factors	Positive effect	Negative effect
Climate		
UV	Protective (immunosuppressive)	
Season	Protective (summer)	Increased risk (summer)
Humidity	Protective (reduce sweating)	Increased risk (exacerbate itch)
Infection	Increased risk	
Air pollutants	Increased risk	
Stress	Increased risk	
Skin irritants	Increased risk	
Skin barrier defect	Increased risk	

Table 3. Summary of flare factors for atopic dermatitis

From: G.H. Nguyen et al., International Journal of Dermatology, 2019, 58, 279–282. <https://doi.org/10.1111/ijd.14016>

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Among the latter include: diet, stress, heat, sweating, damp, pollen exposure, air pollutants, construction materials and dust mites.

It is not surprising that climate change will be expected to influence the complex interplay between many of these factors and the incidence and severity of eczema.

“Taken together, it seems the changing environment, attributable to climate change, is having a profound effect on the epidemiology of AD. Increased temperatures, increased humidity, increased pollen, and air pollution are all associated with changes in the epidemiology and severity of atopic dermatitis.”

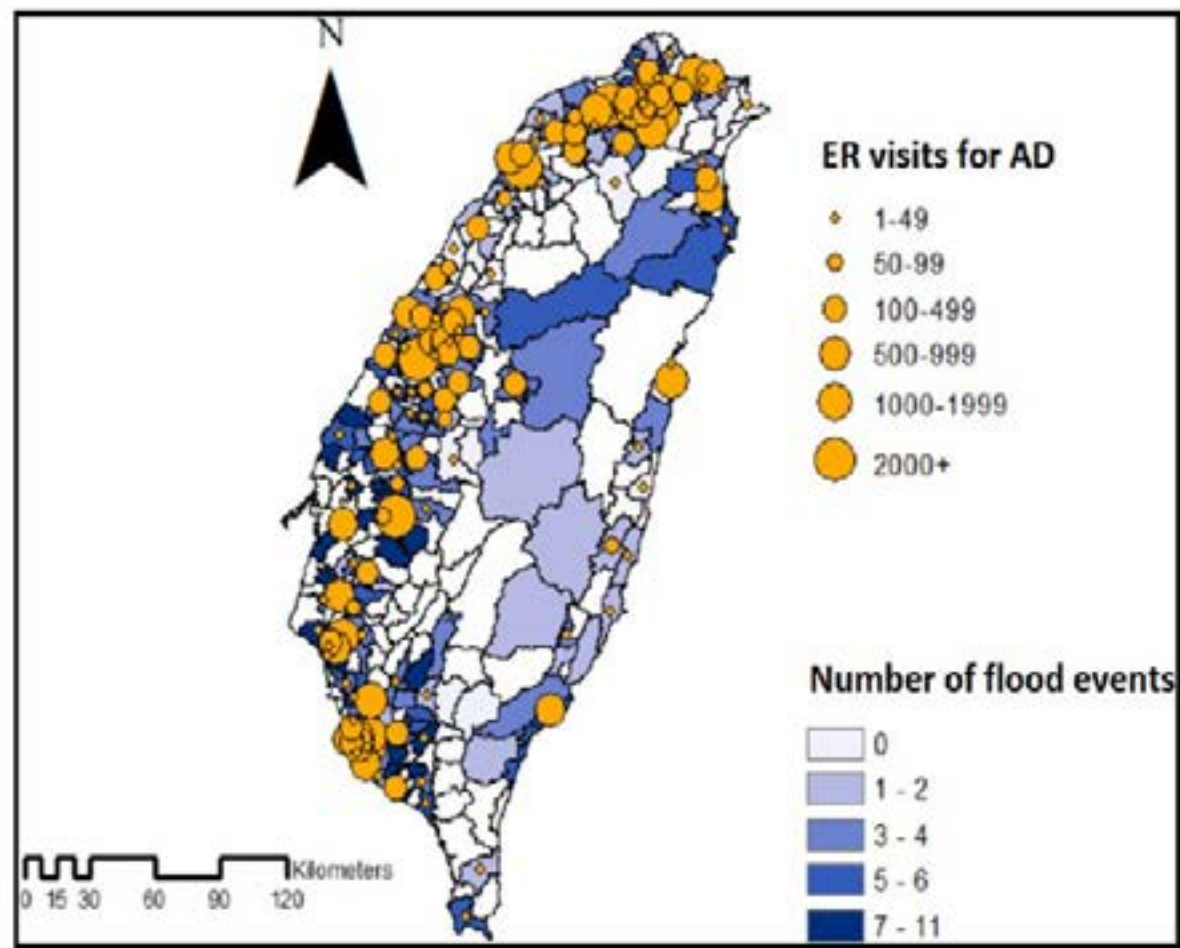


Figure 21. Geographical correlation between emergency room visits for childhood AD and flood events in Taiwan¹.

¹From: N. Chen et al., Science of The Total Environment, 15 June 2021, 773, 145435.
<https://doi.org/10.1016/j.scitotenv.2021.145435>

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Climate change-related flooding events are anticipated to increase the prevalence of atopic dermatitis, amongst other chronic inflammatory skin diseases.

For example, a correlation between emergency room visits for childhood AD and flooding events in Taiwan has been ascribed to increases in environmental mold levels (figure 21)¹.

Prolonged submergence in inundated floodwater is also known to be one of the risk factors for keratinocytes damage, conducive to

inflammation and irritation without activation of the immune cascade.

Psychodermal effects, primarily stress, caused as a result of uncontrollable environmental conditions such as flooding, have been shown to aggravate primarily underlying diseases

including AD, alopecia, prurigo nodularis, psoriasis and vitiligo².

²From: T. Tempark et al., International Journal of Dermatology, 2013, 52, 1168-1176.

→ | <https://doi.org/10.1111/ijd.12064>

Storm-related flooding has also been shown to lead to immediate increase in the number of **cellulitis** patients, according to a study of a 2013 typhoon aftermath in Taiwan (figure 22).

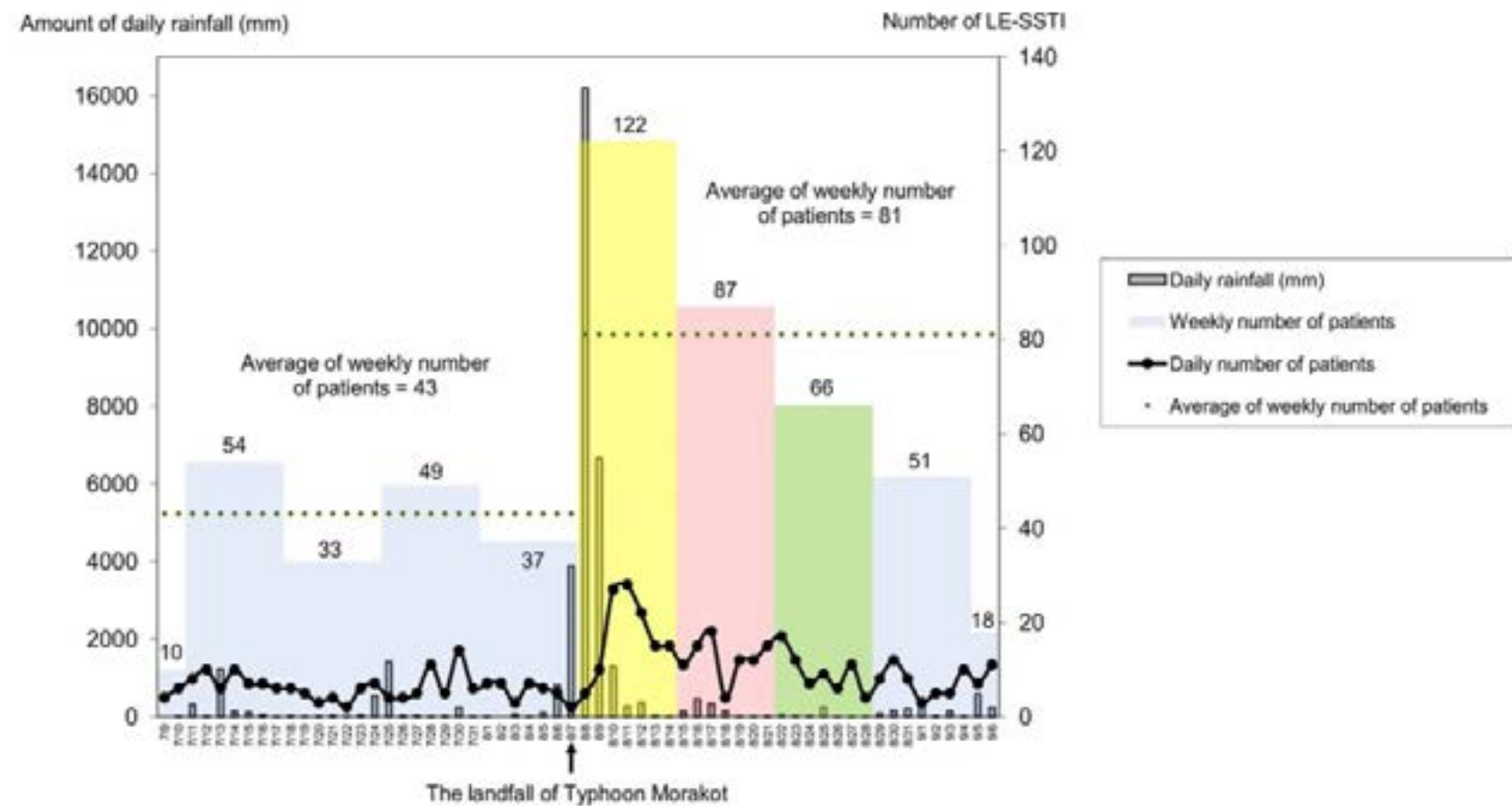


Figure 22. Daily and weekly numbers of lower extremity cellulitis patients and the corresponding amount of daily rainfall.

From: P. Lin et al., PLoS ONE, 2013, 8, (6), e65655.
<https://doi.org/10.1371/journal.pone.0065655>

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The number of patients almost doubled during the 30 day period following the typhoon landfall.

Immersion of lower limbs in floodwater appeared to be a risk factor of lower extremity

cellulitis but had similar effects on individuals with and without

immune compromising diseases. Antibiotic treatments that are effective to both Gram-positive cocci and Gram-negative bacilli were found to be effective for these patients.

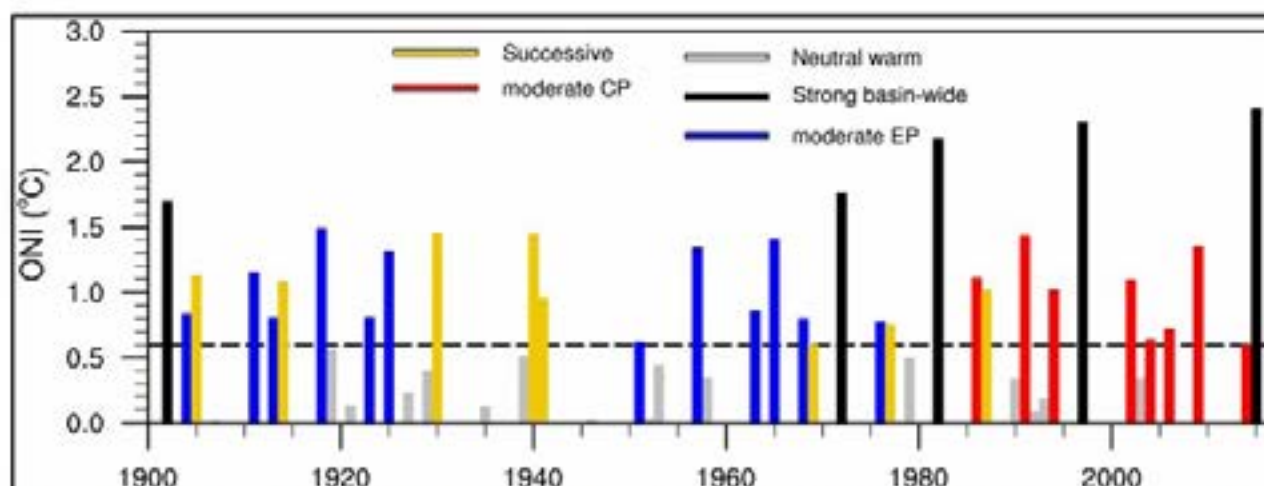
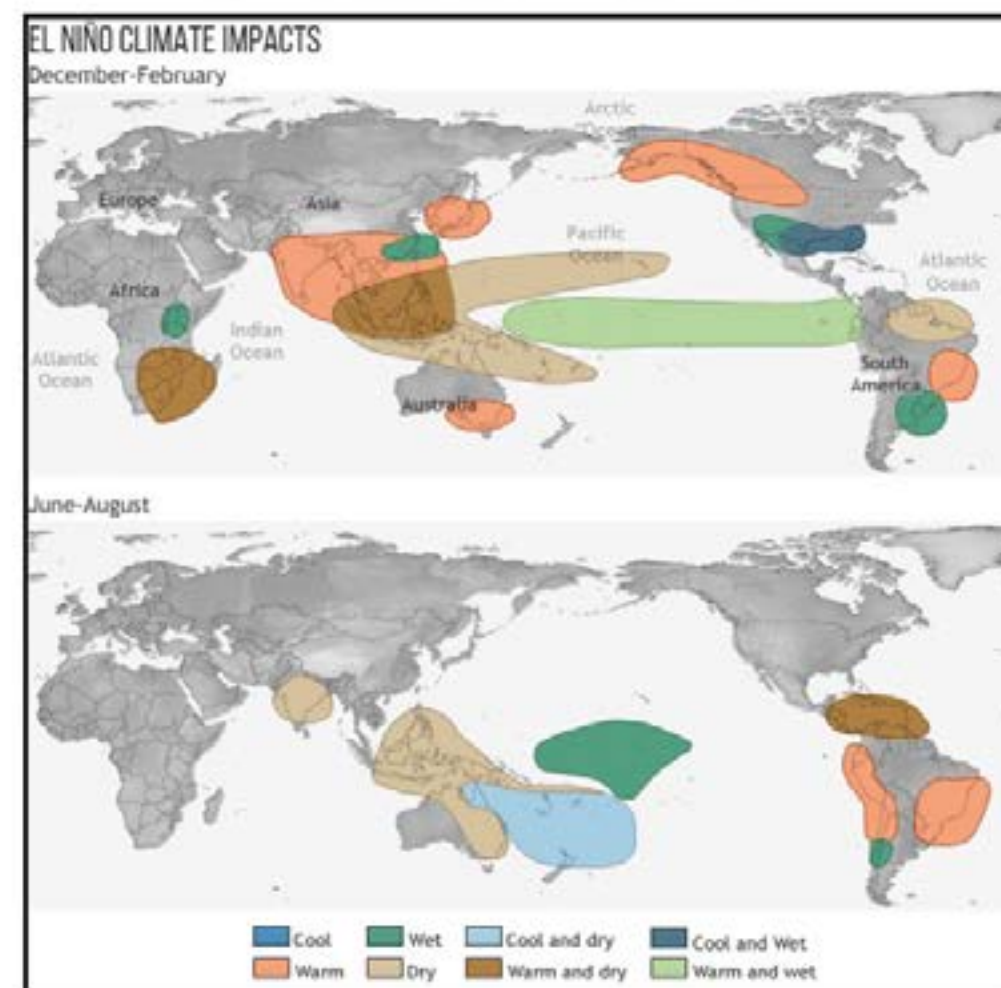


Figure 24². Increases in intensity (ONI = oceanic Niño index, high value = more intense) and frequency of El Niño, post 1960. Colours represent different regions affected by a particular El Niño event.

²From: B. Wang et al., PNAS, Nov. 5, 2019, **116**, (45), 22512–22517. <https://doi.org/10.1073/pnas.1911130116>

Figure 23. Climatic impacts of El Niño



¹From: L.K. Andersen and M. D. P. Davis, International Journal of Dermatology, 2015, **54**, 1343–1351. <https://doi.org/10.1111/ijd.12941>

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Increased prevalence of numerous diseases including actinic keratosis, eczema, and rosacea have been observed to correlate with occurrences of the El Niño ocean warming weather phenomenon (figure 23), associated with temperature increases, humidity changes

and natural land cover change in Kenya and Peru¹.

Recent work² finds increases in both intensity and frequency of El Niño post-1960, indicating further exacerbation of these diseases as a result of climate change (figure 24).

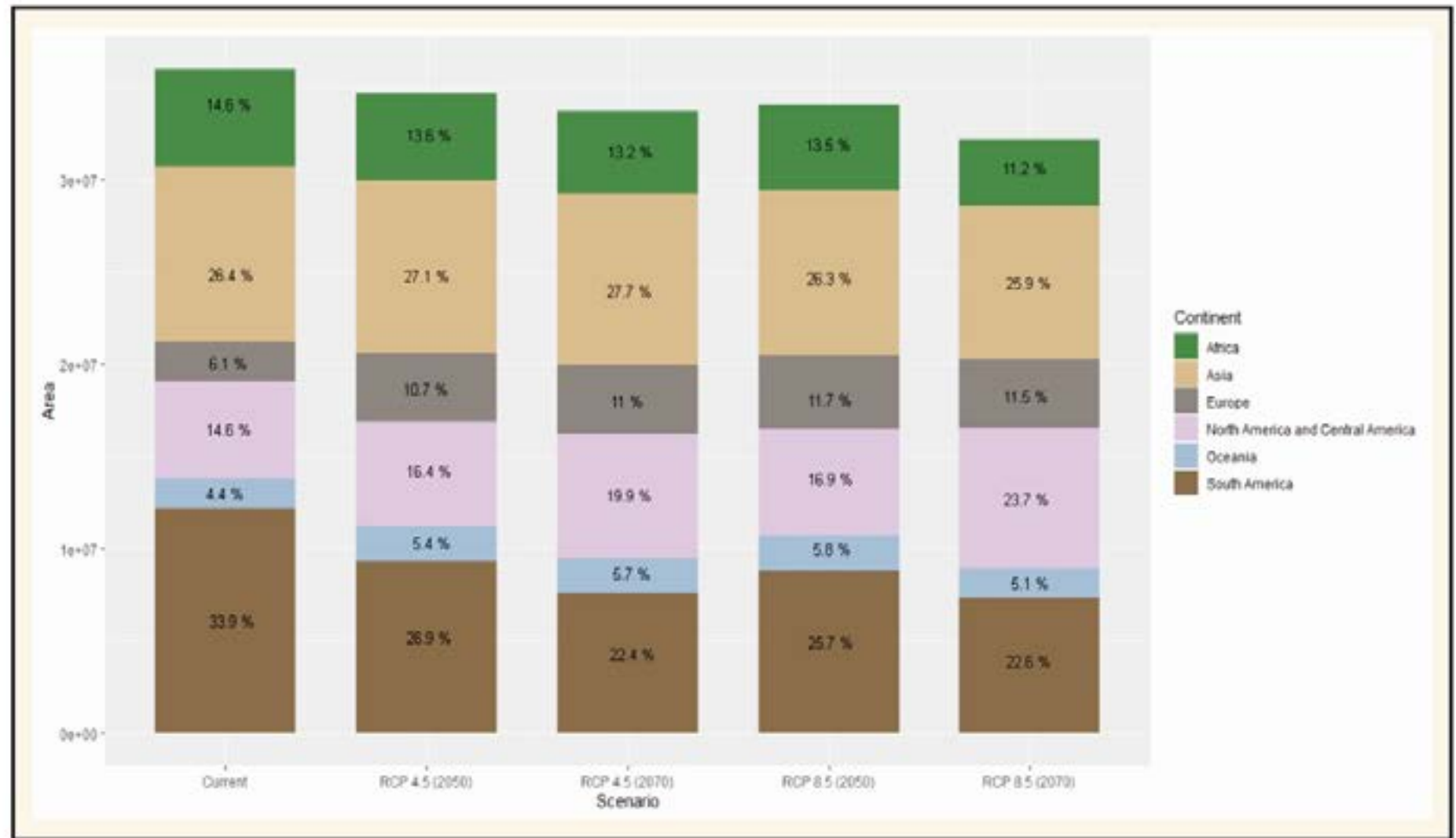


Figure 25. Area of potential distribution of *Hermetia illucens* (Black soldier fly) in five climate change scenarios.
Note: large areal distribution increases for Europe under all scenarios.

From: A. Pazmiño-Palomino, Biodiversity Data Journal, 2022, **10**, e90146.
<https://doi.org/10.3897/BDJ.10.e90146>

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Epidemiological data on cutaneous myiasis are scant. In the future however, climate changes that cause migration of new fly species from tropical and subtropical countries could increase the incidence of this condition and modify its epidemiologic characteristics in Europe.

The invasion of new fly species in Europe, which live obligatorily parasitically or are close relatives of myiasis-causing species, is currently being observed and predicted to accelerate under predicted climate change scenarios (figure 25). Thus it might be expected that, with rising temperatures, a noticeable increase in

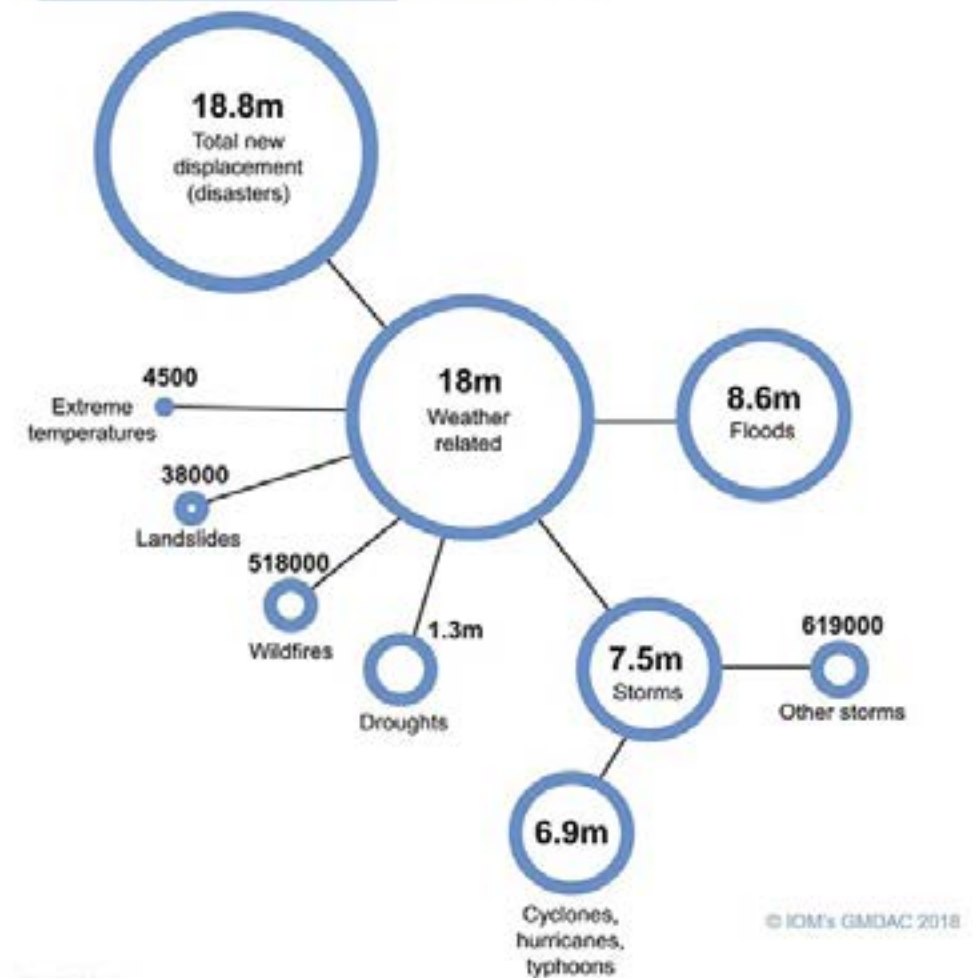
the number of myiasis cases in Europe is to be assumed.

5.3 Infectious dermal diseases (excluding vector-borne dermal diseases)

- Contact with pathogens on/in solids or fluids only
- Contact with both airborne and solid/fluid based pathogens
- Contact with insects only

From: J.Semenza and K. Ebi, Travel Med, 2019, 26, (5), taz026.
<https://doi.org/10.1093/itm/taz026>

DISPLACEMENT PER DISASTER



Source: IDMC, 2018.

Figure 26. Internal displacement by environmental disasters in 2017.

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In order to examine the current state of knowledge of the effects of climate change on this disease type, we will categorise them according to transmission mode:

- Contact with pathogens on/in solids or fluids only
- Contact with both airborne and solid/fluid based pathogens
- Contact with insects only

In all categories there may also be an additional human migration/displacement/travel contribution to the transmission mode.

Transmission by contact with pathogens on/in solids or fluids only

Disease	Climate change factor(s) affecting the disease	Outcome/predicted effect on the disease	Reference
Herpes simplex	Sun exposure, stress from extreme weather events	Disease flare-up/aggravation	S.R. Cuddy <i>et al.</i> , <i>eLife</i> , 2020, <u>9</u> , e58037. https://doi.org/10.7554/eLife.58037
Gonorrhoea	Temperature increase, human migration	Increase in number of cases	R. Suresh, 2021, USFCA Master's Theses, 1382. https://repository.usfca.edu/thes/1382 . Accessed 11 th June 2023
Impetigo	Flooding	Increase in number of cases	E. Parker, <i>J. Climate Change and Health</i> , 2022, <u>8</u> , 10016. https://doi.org/10.1016/j.joclim.2022.100162
Marburg	Temperature increase leading to spread of host animals	Geographical spread of disease	F. Kritz, https://www.wbur.org/npr/1167093290/theres-a-second-outbreak-of-marburg-virus-in-africa-climate-change-could-be-a-fa Accessed 11 th June 2023
Monkeypox	Natural land cover change and deforestation leading to increased human/animal host contact	Geographical spread of disease	B. Hugh <i>et al.</i> , https://climateandsecurity.org/2022/09/monkeypox-and-the-convergence-of-climate-ecological-and-biological-security-risks/ Accessed 11 th June 2023
Ringworm (tinea corporis)	Increased temperature and humidity, flooding	Increase in number of cases	A. Gadre <i>et al.</i> , <i>J. Climate Change and Health</i> , 2022, <u>6</u> , 10015. https://doi.org/10.1016/j.joclim.2022.100156
Shingles	Increased temperature	Increase in number of cases	Y. Choi <i>et al.</i> , <i>Nature Scientific Reports</i> , 2019, <u>9</u> , 12254. https://doi.org/10.1038/s41598-019-48673-5
Syphilis	Human migration due to climate change and war	Geographical spread of disease	J. F. Dayrit, <i>Int. J. Dermatology</i> 2022, <u>61</u> , 127–138. https://doi.org/10.1111/ijd.15543
Vibrio vulnificus	Temperature increase and flooding-induced changes in estuarine salinity	Increased incidence and geographical distribution range	C. Baker-Austin <i>et al.</i> , <i>Env. Microbio. Reports</i> , 2010, (1), <u>2</u> , 7–18. https://doi.org/10.1111/j.1758-2229.2009.00096.x
Viral warts	Increase in temperature due to El Niño, human migration	Increase in number of cases	E.L. Gutierrez <i>et al.</i> , <i>An. Bras. Dermatol.</i> , 2010, (4), <u>85</u> , 461-8. https://doi.org/10.1590/S0365-05962010000400007

Transmission by contact with both airborne pathogens and those on/in solids or fluids.

Disease	Climate change factor(s) affecting the disease	Outcome/predicted effect on the disease	Reference
Chickenpox	Temperature, sun exposure, and rainfall	Increasing incidence with decreasing temperature, increasing sun exposure and increasing rainfall	Y. Yang <i>et al.</i> , BMC Infectious Diseases, 2016, 16 , 179. https://doi.org/10.1186/s12879-016-1507-1
Diphtheria	Human migration	Increasing incidence due to population displacement resulting from natural disasters	European Centre for Disease Prevention and Control, 6 Oct. 2022, Stockholm. https://www.ecdc.europa.eu/en/publications-data/increase-reported-diphtheria-cases-among-migrants-europe-due-corynebacterium Accessed 11 th June 2023.
Hand-foot-and-mouth disease	Temperature increase	Increasing incidence and prolonged outbreak length	S.J. Coates <i>et al.</i> , Int. J. Dermatology, 2019, 58 , 388–399. https://doi.org/10.1111/ijd.14188
Measles	Temperature, humidity and human migration/travel	Increasing incidence within the optimum temperature range 18°C to 20°C. Increasing incidence with decreasing humidity	Q. Yang <i>et al.</i> , Human Vaccines & Immunotherapeutics, April 2014, 10 (4), 1104–1110. http://dx.doi.org/10.4161/hv.27826
Rubella	Temperature and humidity/precipitation	Increasing incidence with decreasing temperature and decreasing humidity	Y. Ma <i>et al.</i> , Am. J. Trop. Med. Hyg., 2021, 104 , (1), 166–174. https://doi.org/10.4269/ajtmh.20-0585

Transmission by contact with insects only

Disease	Climate change factor(s) affecting the disease	Outcome/predicted effect on the disease	Reference
Cutaneous larva migrans	Temperature increase and human migration	Increasing incidence	S.H. Choi <i>et al.</i> , International Journal of Dermatology, 2023, 62 , 681–684. https://doi.org/10.1111/ijd.16636
Cutaneous myiasis	Temperature increase and human travel	Increased incidence and geographical distribution range due to expansion of climatic regions favourable for <i>Diptera</i> order flies	E. Andreattas and L. Bonavina, European Surgery, 2022, 54 , 289–294. https://doi.org/10.1007/s10353-021-00730-y
Scabies	Temperature and humidity	Increased incidence with decreasing temperature and increasing humidity	J.M. Liu <i>et al.</i> , Parasite, 2016, 23 , 54. http://dx.doi.org/10.1051/parasite/2016065

5.4 Skin malignancies



Risk factors

1. Exposure to excess ultraviolet radiation (UVR).
2. Air pollution $PM_{2.5}$ (particulate matter $<2.5\mu m$) and smaller particles.
3. Exposure to arsenic and its compounds

Current knowledge on this type of disease is quite good. The three main causes of skin cancers are:

1. Exposure to excess ultraviolet radiation (UVR). By far the largest contributor to skin cancer. In terms of climatic factors, this obviously stems from the amount of sun that unprotected skin receives. Some ethnic groups, such as fair-skinned people, are more at risk. Stratospheric ozone (O_3) plays a major part in protection from UVR.
2. Air pollution $PM_{2.5}$ (particulate matter $<2.5\mu m$) and smaller particles. These particles penetrate the epidermis and may pass trans-dermally via follicular and eccrine structures. Furthermore, the carcinogenicity

of $PM_{2.5}$ is enhanced when it forms aerosols with adsorbed toxic metals and polycyclic aromatic hydrocarbons. Heatwaves and fires due to climate change mainly contribute to this cause.

3. Exposure to arsenic and its compounds. This occurs mainly by ingestion of contaminated drinking water. In the context of climate change effects, this contamination is most likely to happen as a result of flooding or drought.

EXCESS UVR

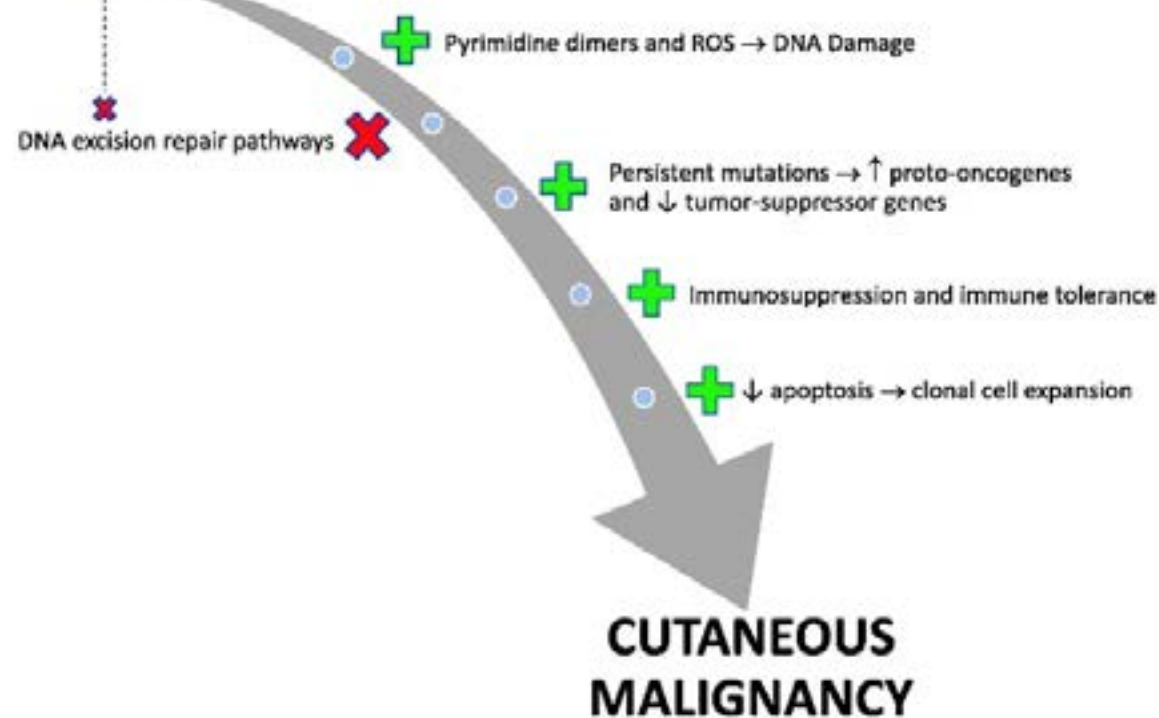


Figure 27. Photocarcinogenesis: exposure of the skin to UVR results in DNA damage via the formation of pyrimidine dimers and reactive oxygen species. DNA repair may reverse some damage, but these mechanisms are overwhelmed when UVR exposure is excessive. This allows the progression of mutagenesis, immune suppression, and clonal cell expansion, thus promoting tumor formation

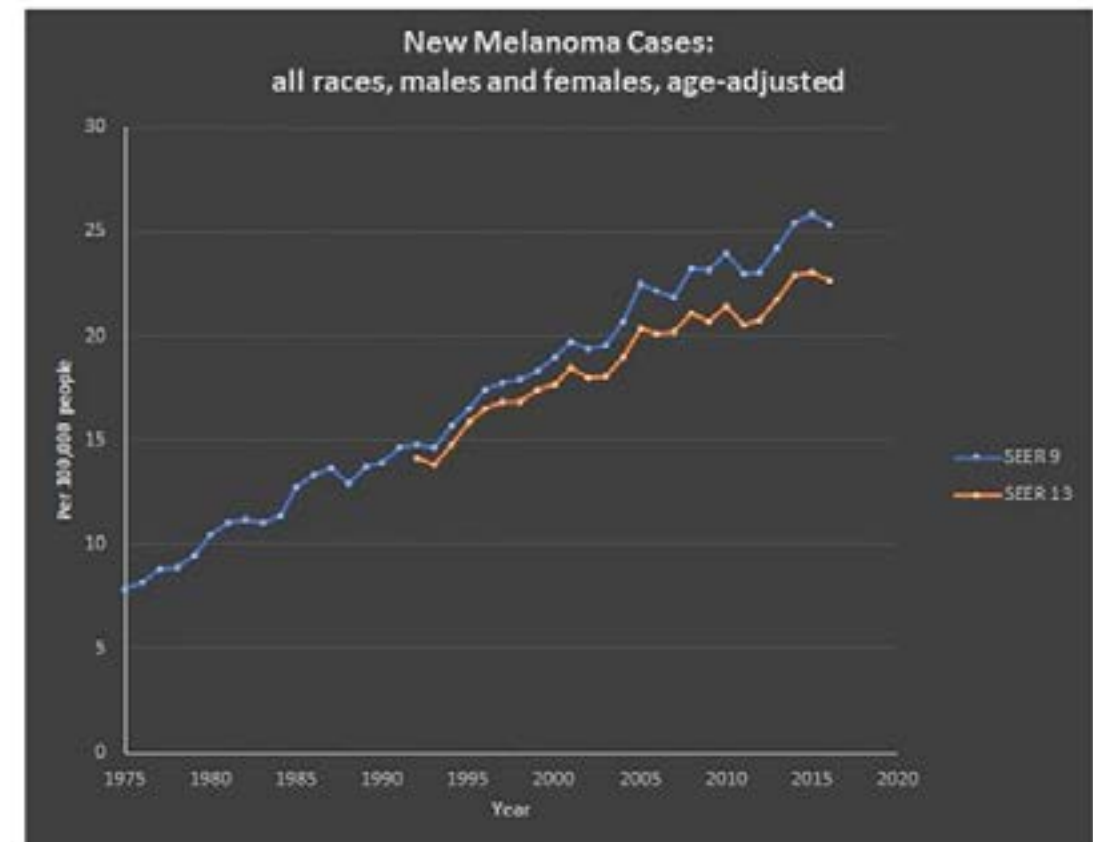


Figure 28. Surveillance, Epidemiology, and End Results (SEER) 9 and 13 data for new cutaneous malignant melanoma cases per 100,000 people in the U.S. SEER 9 and 13 refer to two geographical areas surveyed.

From: E.R. Parker, Int. J. Women's Dermatology, 2021, 2, 17–27.
<https://doi.org/10.1016/i.ijwd.2020.07.003>

Excess UVR exposure leads to cutaneous malignancy via a multi-step process of photocarcinogenesis (figure 27). Incidence of skin cancer increased substantially in the latter half of the 20th century and continues to increase (figure 28) despite efforts at reduction,

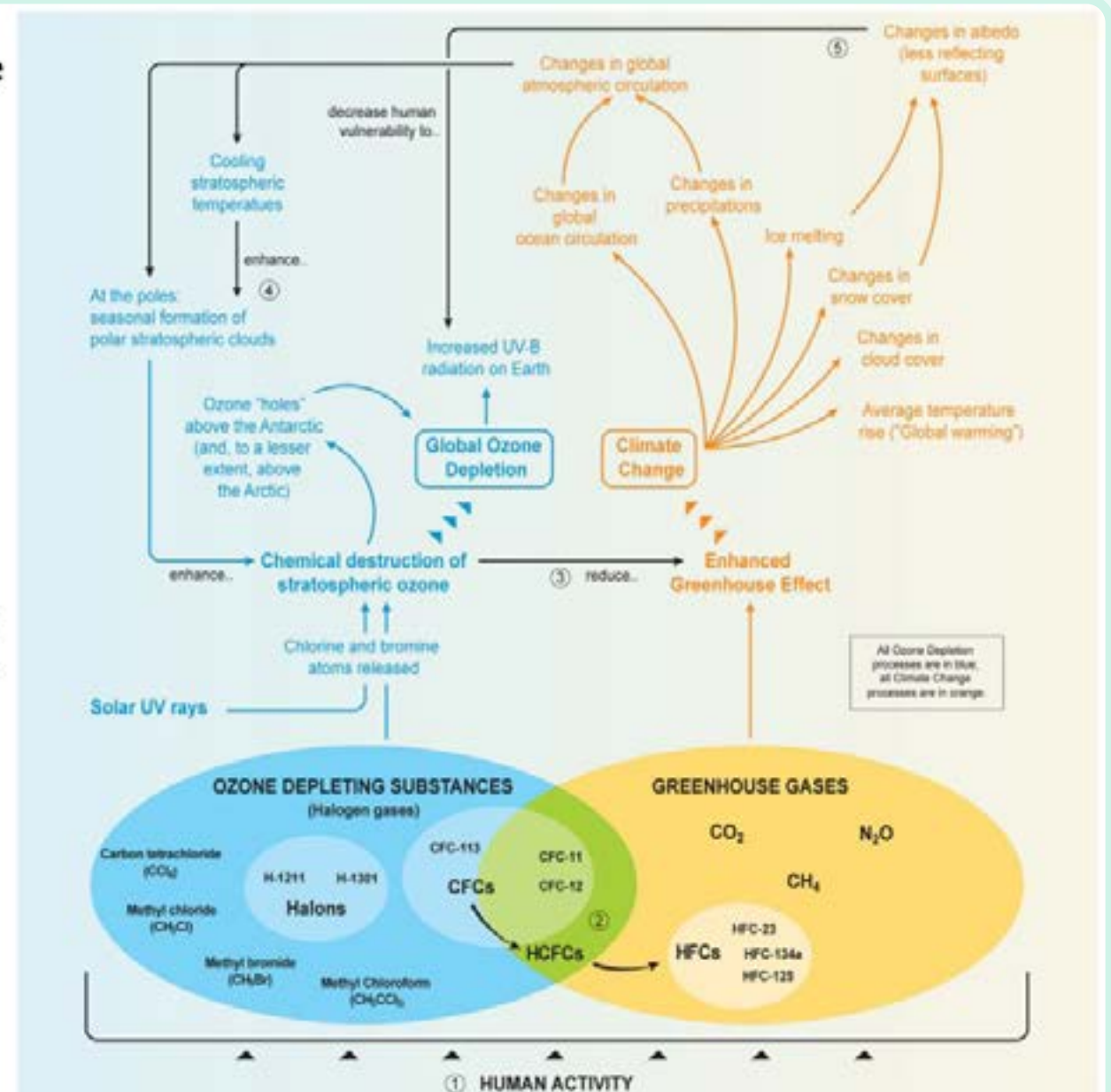
such as reversal of stratospheric ozone depletion.

The role of stratospheric ozone in UVR protection and climate change is complex since ozone is both an efficient UVR absorber (good) and a greenhouse gas (bad).

- ① Both processes are due to human-induced emissions.
- ② Many ozone depleting substances are also greenhouse gases, like CFC-11 and CFC-12. HFCs, promoted to substitute CFCs, are sometimes stronger greenhouse gases than the CFCs they are replacing, but do not deplete the ozone layer. This fact is taken into account in the negotiations and decisions in both the Montreal and the Kyoto Protocol.
- ③ Ozone itself is a greenhouse gas. Therefore, its destruction in the stratosphere indirectly helps to cool the climate, but only to a small extent.
- ④ The global change in atmospheric circulation could be the cause of the recently observed cooling of stratospheric temperature. These low temperatures drive the formation of polar stratospheric clouds above the poles in the winter, greatly enhancing chemical ozone destruction and the formation of the "hole".
- ⑤ Human vulnerability to UV-B radiation is related to the albedo. The global warming context reduces white surfaces that are more likely to harm us.

Figure 29. Schematic illustration of the interactions between stratospheric ozone depletion and climate change

From: E.R. Parker, Int. J. Women's Dermatology, 2021, 7, 17–27.
<https://doi.org/10.1016/j.ijwd.2020.07.003>



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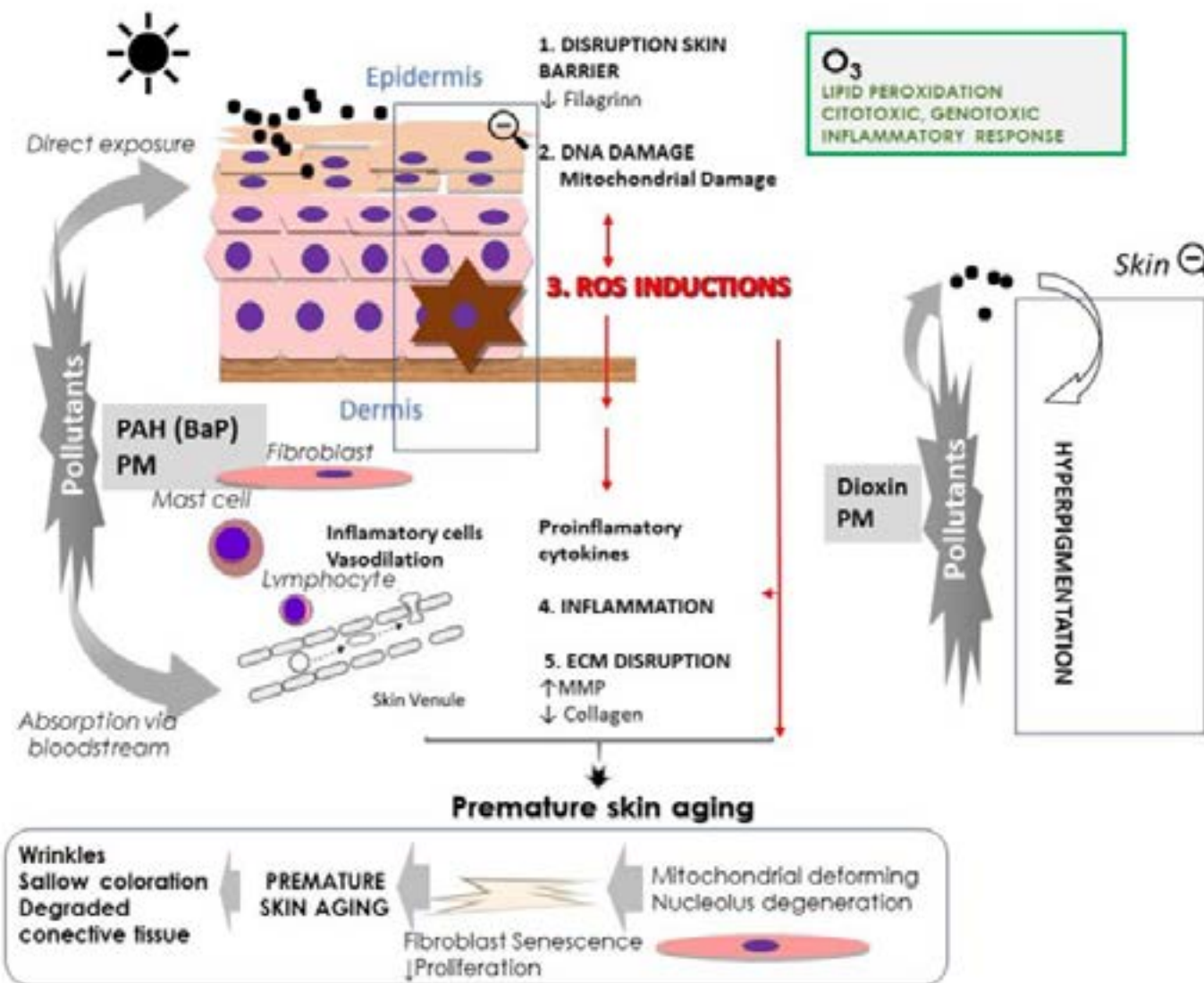


Figure 30. Skin responses to air pollution and UVR. (PAH = polyaromatic hydrocarbons, ECM = extra cellular matrix, ROS = reactive oxygen species)

From: C. Parrado, Frontiers in Pharmacology, 2019, **10**, 759.
<https://doi.org/10.3389/fphar.2019.00759>

Mechanisms	Biological effects		Effects on the skin	
	Aging/pollutants		Aging/pollutants	
Activation of AhR	↑/▲	Increase of melanogenesis	↑/▲	Hyperpigmentation
Generation of ROS	↑/▲	DNA damage. Lipid peroxidation.	↑/▲	Wrinkles
Induction of inflammatory cascade	↑/▲	Decrease collagen	↑/▲	Delayed healing skin
Disruption of skin barrier	↑/▲	Increase MMPs	↑/▲	Dry skin Exacerbation of skin diseases

*Table 4. Common mechanisms and effects observed in skin aging (↑) and in skin damage after air pollution exposure (▲).
(AhR = aryl hydrocarbon receptors, MMPs = matrix metalloproteinases).*

From: C. Parrado, *Frontiers in Pharmacology*, 2019, **10**, 759.
<https://doi.org/10.3389/fphar.2019.00759>

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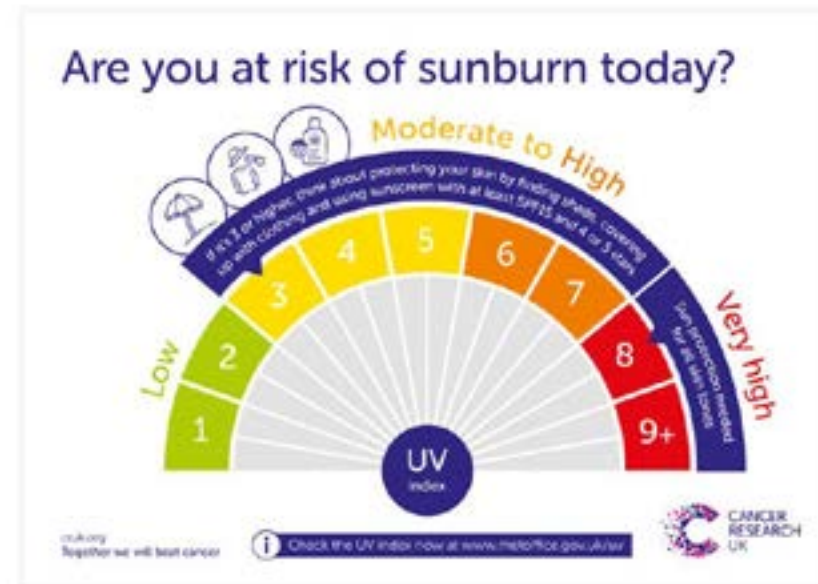
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6. Possible prevention and mitigation methods

Methods for avoiding or ameliorating these effects can be grouped in three broad categories:

- Environmental
- Societal
- Technological



The impact of air pollution on allergy and dermal diseases could be mitigated by:

- Strict controls on combustion exhaust gases from vehicles, domestic appliances, and industrial sources, particularly in or adjacent to centres of population.
- Elimination of internal combustion engine vehicles from highly populated urban environments.
- Enhanced surveillance and management of rural areas, particularly forests, to prevent and detect wildfires.
- Rapid response, internationally co-ordinated systems for control of wildfires.

The effects of flooding as a major contributor to dermal diseases should be lessened by:

- Identification of areas most at risk from major flooding, with implementation of flood abatement measures, where possible.
- Adoption of appropriate plans for the prompt evacuation of populations prior to flooding events.

6.1 Environmental control methods

In addition to the obvious mitigation of climate change effects by a global reduction in greenhouse gas emissions, there are a number of specific measures that could be taken in relation to allergy and dermal diseases. In the case of pollen allergies, some straightforward actions can be taken as regards flora management in or adjacent to major centres of population:

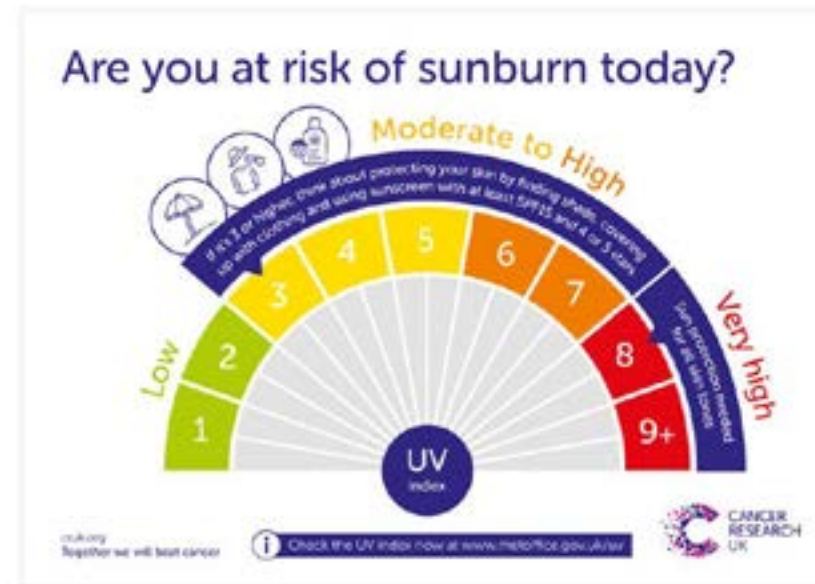
- Use entomophilous plants, which rely on insect pollination and produce smaller pollen quantities.
- Plant trees and shrubs that flower in summer or winter, avoiding those that flower in spring, reducing the impact of spring pollination.

- Prune hedges and mow lawns before flowering and pollen emission.
- Cut highly allergic grasses before flowering and pollen emission.
- Arrange for mowing and management of green areas on days that are not windy, and preferably at night.
- Eliminate highly allergenic plant species from public places.

6. Possible prevention and mitigation methods

Methods for avoiding or ameliorating these effects can be grouped in three broad categories:

- Environmental
- Societal
- Technological



Improved public education regarding hazards of and access to methods of risk minimisation for skin malignancies:

- Publication of up-to-date information on lifestyle and dietary actions for risk minimisation. For example, adoption of selenium rich diets for fair-skinned populations, awareness of implications for risk as a side effect from certain medications, etc.
- Awareness of real-time environmental information, particularly regarding personal exposure to UVR.
- Better access to affordable UVR skin protection methods.

6.2 Societal control methods

Enhancement of public awareness of climate change effects on allergy and dermal diseases, with better access to appropriate treatments:

- Education programmes in schools and colleges.
- Public information campaigns in conventional and social media.
- Real-time information by mobile personal health apps, e.g. along the lines of the national COVID Tracker apps developed within the EU. Could these be integrated into a single EU health app with sections for allergy and dermal diseases?

- Improved public access to medical treatment and vaccines for allergy and dermal diseases.

For allergy and chronic inflammatory dermal diseases:

- Development of a better understanding of the psychological, social, and environmental effects of migration (both country internal and international) on these diseases.

In the case of infectious dermal diseases:

- Effective travel and controls on people migrating/travelling from infected areas, with appropriate medical treatment, if required.

6.3 Technological control methods

- Implementation of automated pollen and spore monitoring networks that are integrated with realistic atmospheric composition models to predict high aeroallergen climate events.
- Further development and roll-out of allergen-specific immunotherapies (AITs).
- Further development and roll-out of bacteriotherapies for chronic inflammatory dermal diseases.

Vaccine development for dermal diseases, where applicable (see table 5). Of the 24 applicable diseases discussed here, 8 (33%) have vaccines available, and 9 (56%) of the remaining 16 have vaccines under development.

Disease	Vaccine available?	Vaccine under development?
Acne	No	Yes
Actinic keratosis	No	Yes
Alopecia areata	No	No
Cellulitis	No	No
Chickenpox	Yes	-
Diphtheria	Yes	-
Eczema	No	No
Gonorrhea	No	No
Hand-foot-and-mouth disease	No	Yes
Herpes simplex	No	Yes
Impetigo	No	Yes
Marburg	No	Yes
Measles	Yes	-
Monkeypox	Yes	-
Prurigo nodularis	No	No
Psoriasis	No	Yes
Ringworm	Yes	-
Rosacea	No	No
Rubella	Yes	-
Shingles	Yes	-
Syphilis	No	Yes
Vibrio vulnificus	No	Yes
Viral warts	Yes	-
Vitiligo	No	No

Table 5. Current status of dermal disease vaccine development

7. Key take home messages

- Most (89%) of the major allergy and dermal diseases discussed here are affected by climate change in various ways and for a number of reasons.
- All of the 10 main anthropogenic climate change hazards cause aggravation of these diseases to a greater or lesser extent. These are: warming, heatwaves, fires, floods, storms, precipitation, sea level rise, natural land cover change, drought, and ocean climate change. In many cases, more than one hazard is at play for a given disease.
- Climate change effects have been shown to or are predicted to show changes in disease incidence, severity, frequency/seasonal duration, and/or geographical range.
- For allergy diseases, the major climate change-originating aggravating factors are: air pollution, biological aeroallergens (pollen, etc.), and temperature and humidity increases.

7. Key take home messages

- For chronic inflammatory dermal diseases, the major climate change-originating aggravating factors are: increases in temperature, humidity and UVR exposure, flooding, storms, and psychological effects due to natural disasters.
- For infectious dermal diseases, the major climate change-originating aggravating factors are: temperature and humidity increases, flooding, and human migration caused by climate change.
- For skin malignancies, the major climate change-originating aggravating factors are: excess UVR exposure and nano-particulate air pollution.
- There is often a complex interplay between these various climatic hazards and the causes/triggers for a given disease.

7. Key take home messages

- Prevention and mitigation of climate change-aggravated allergy and dermal diseases revolves around environmental, societal, and technological control methods, including:
1. Careful management/control of flora in and around highly populated areas.
 2. Elimination of combustion air pollution sources in urban environments.
 3. Surveillance, management and control of vegetation in rural areas to prevent wildfires.
 4. Implementation of flood management and abatement measures.
 5. Enhanced public awareness of allergy and dermal disease causes, prevention, and treatment.
 6. Effective travel controls on people migrating/travelling from areas with endemic infectious skin diseases.
 7. Automated monitoring methods and improved predictive atmospheric models for aeroallergens.
 8. Development of allergen-specific immunotherapies, bacteriotherapies, and vaccines.

8. Essential reading for this lesson

1. G. D'Amato and L. Cecchi, "Effects of climate change on environmental factors in respiratory allergic diseases", *Clinical and Experimental Allergy*, 2008, 38, 1264–1274. <https://doi.org/10.1111/j.1365-2222.2008.03033.x>
2. P.J. Beggs, "Adaptation to Impacts of Climate Change on Aeroallergens and Allergic Respiratory Diseases", *Int. J. Environ. Res. Public Health*, 2010, 7, 3006-3021. <https://doi.org/10.3390/ijerph7083006>
3. M.F. Isler *et al.*, "Climate change, the cutaneous microbiome and skin disease: implications for a warming world", *Int. J. Dermatology*, 2023, 62, 337–345. <https://doi.org/10.1111/ijd.16297>
4. E. Parker *et al.*, "The dermatological manifestations of extreme weather events: A comprehensive review of skin disease and vulnerability", *J. Climate Change and Health*, 2022, 8, 10016. <https://doi.org/10.1016/j.joclim.2022.100162>

9. Test your knowledge

1. What are the major effects on global society of (a) allergies and (b) dermal diseases?
2. Give two examples of each of the following disease types: (a) allergies; (b) chronic inflammatory skin diseases; (c) infectious skin diseases; and (d) skin malignancies.
3. List three infectious skin disease causes/triggers that are affected by climate change hazards.
4. Draw a simple diagram that shows the interplay of air pollution and climate change in the promotion of allergies.
5. Give one example for each of the three types of skin disease listed in question 2 above, explaining how climate change will aggravate each disease.
6. Give two examples of specific control methods for the prevention/mitigation of climate change aggravation of allergy and dermal diseases, from each of the following control groups:
 - Environmental control
 - Societal control
 - Technological control

Thank you for you attention!

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University of Pécs Medical School – Pécs, Hungary



Center for Health, Exercise and Sport Science – Novi Sad, Serbia



National Public Health Center – Budapest, Hungary



University College Cork – National University of Ireland – Cork, Ireland



Universitatea de Medicina, Farmacie, Stiinta si Tehnologie
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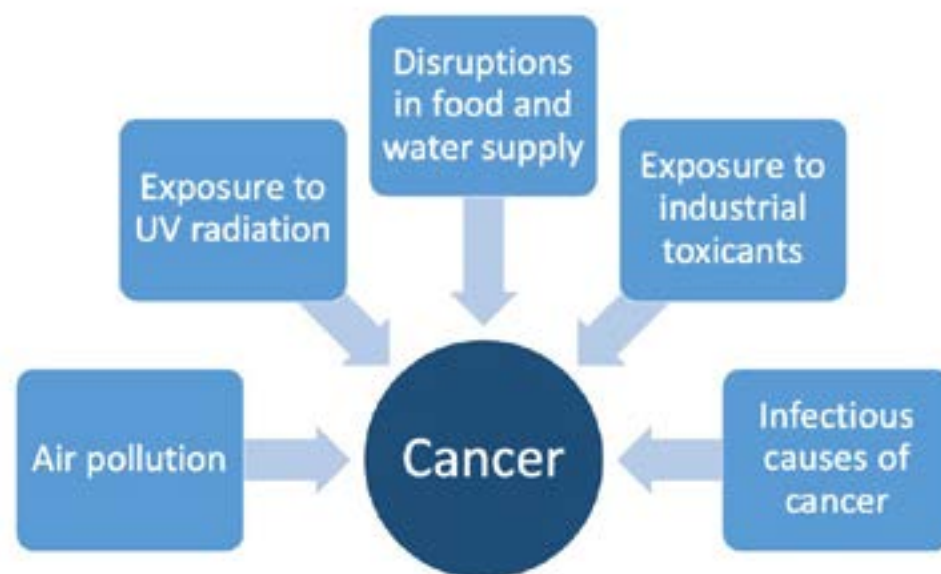
Impact of climate change on cancer, fungal diseases, mycotoxins

Learning outcomes

Upon successful completion of the course students will be able to

- list the principal mechanisms linking climate change to increased cancer incidence;
- name at least four type of cancers possibly associated with climate change;
- explain how climate change can result in increased exposure to UV radiation and ultimately increased incidence of skin cancers;
- describe the influence of climate change on fungal diseases and mycotoxin contamination of food products and two pathologies causally related to exposure to mycotoxins;
- name at least five crops frequently affected by mycotoxin contamination;
- describe the basic strategies to control and mitigate the risk of mycotoxin exposure.

Climate change – cancer: principal mechanisms



DOI: 10.1016/j.1479-2040(2014)00004-4

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The effects of climate change on infectious diseases and conditions caused or exacerbated by limited access to safe and nutritional food and water are relatively well known.

The effects of climate change on chronic diseases such as cancer are less clear.

The potential effects of climate change on cancer incidence were first predicted in the 1990s (Sir Richard Doll – adverse effects of the accumulation of greenhouse gases).

Most literature published in the past 15 years.

Causal relationship more complex

Longer time between exposure and chronic diseases

Temporal relationship more difficult to prove

Cancer trends are on the rise

Distinguishing between the effect of climate change related factors and other carcinogens is a challenge

Cancers possibly associated with climate change



DOI: 10.1016/S1470-2045(20)30448-4

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Lung cancer top cause of cancer mortality worldwide

Lung, bronchus, and tracheal cancers – 1.9 million deaths in 2017 globally

Tobacco consumption still the first cause of cancer mortality

The impact of air pollution is markedly increasing

Human activity leading to more severe air pollution, contributing to climate change

All forms of pollution cause 43% of lung-cancer deaths

Particulate air pollution causes 15% of all lung cancer deaths (20% increase during the last three decades)

International Agency of Research on Cancer, 2013 – classified air pollution as group 1 carcinogen (sufficient evidence to establish causality)

Carcinogenic elements – NO₂, SO₂, O₃, PM₁₀, PM_{2.5}

PM_{2.5} and O₃ – the most useful indicators for monitoring air pollution

PAHs – IARC carcinogens (group 2A, 2B) reach the alveoli bound to PM_{2.5}

Studies during the 21 century show PM air pollution linked to increased premature death from lung cancer worldwide (except Africa)

10 µg/m³ elevation in PM_{2.5} estimated to an adjusted hazard ratio of 1.13 (95% CI 1.07–1.20) (controlled for age, sex, and smoking status)

Carcinogenic effect of tropospheric ozone, less known (see later the role of stratospheric ozone)

Climate change estimated to increase PM pollution through increased wildfires (increasing temperature, droughts)

Wildfire smoke – PM_{2.5}, PAHs, benzene, formaldehyde (known carcinogens)

Air pollution may cause other types of cancers (less evidence)

Some studies linking PAHs, NO₂ to early life development and breast cancer risk

One study linked PM_{2.5} and other air pollutants to gastric cancer

Air pollution-related lung cancer may be reduced by reducing air pollutant emissions

→ https://www.iarc.who.int/wp-content/uploads/2018/07/pr221_E.pdf

Accessed: 13.02.2023

→ DOI: 10.1016/j.envres.2019.108924

→ DOI: 10.1016/S1470-2045(20)30448-4.

→ DOI: 10.1007/s40471-018-0143-2

→ DOI: 10.1016/j.jes.2019.09.025

Particulate Matter (PM) – EPA Classification

PM10 – large inhalable particulates

- Diameter $<10\text{ }\mu\text{m}$; limit value for annual mean: $40\text{ }\mu\text{g}/\text{m}^3$

PM2.5 - fine inhalable particulates

- Diameter $<2.5\text{ }\mu\text{m}$; limit value for annual mean: $20\text{ }\mu\text{g}/\text{m}^3$

PM0.1 - ultrafine particulates, nanoparticles

- Diameter $<0.1\text{ }\mu\text{m}$ (subcategory of PM2.5); no specific regulations

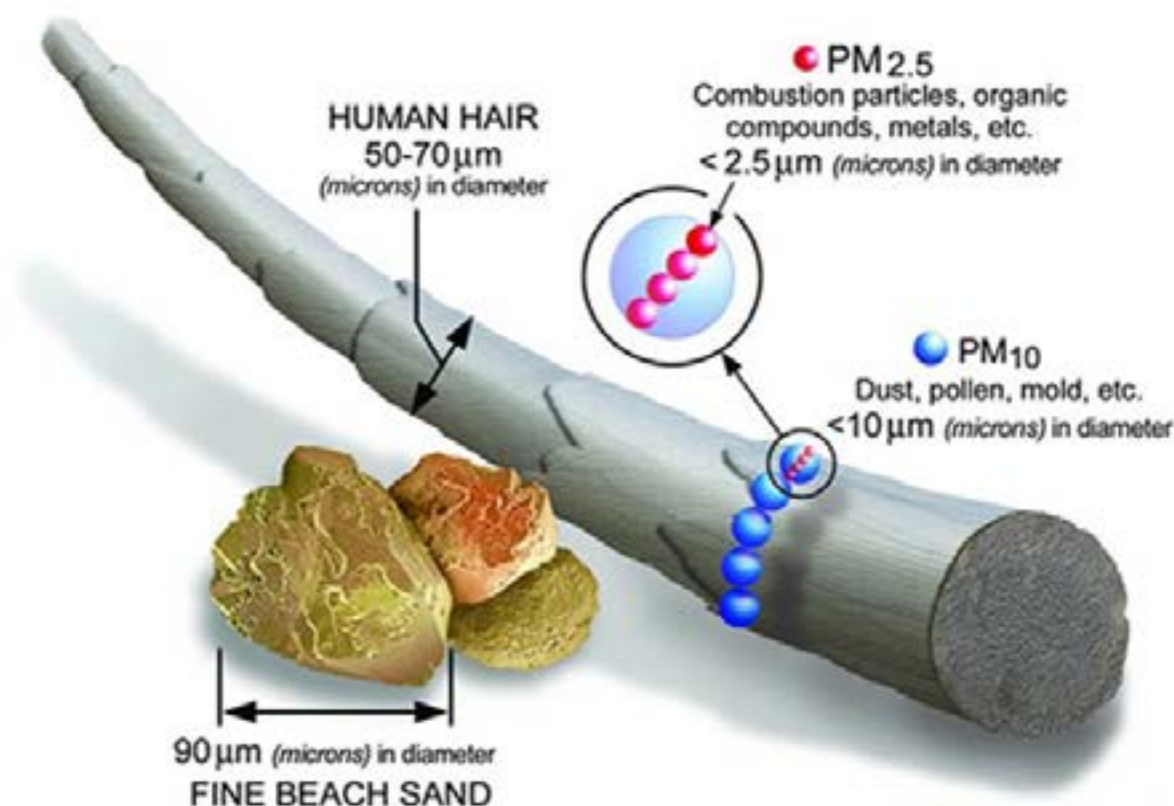


Image courtesy of the U.S. EPA

www.eea.europa.eu/themes/air/air-quality/resources/air-quality-map-thresholds Accessed 20.03.2023.

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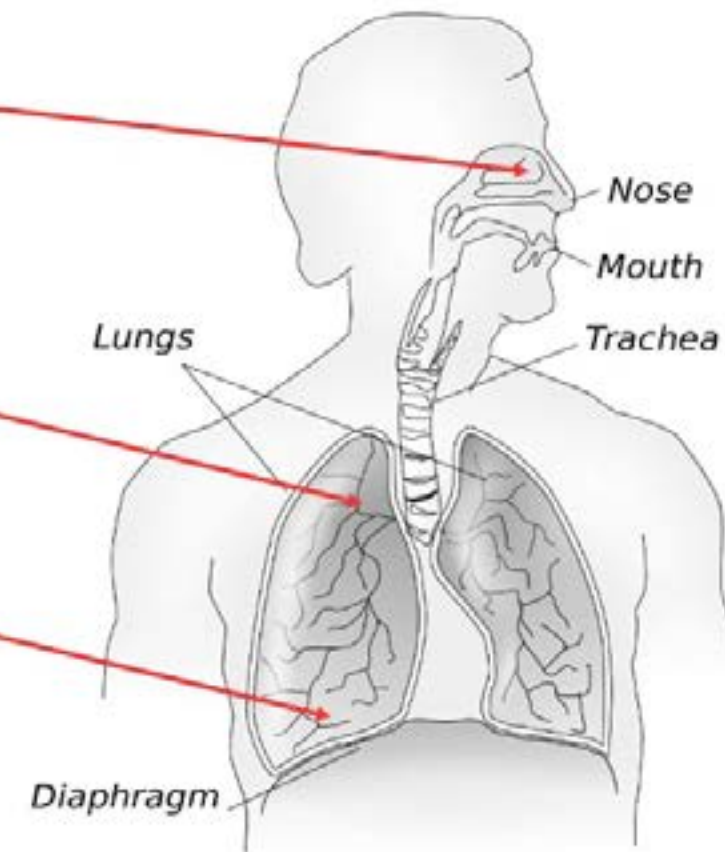
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Particulate Matter – Size vs Penetration

Determines the extent to which they penetrate into the respiratory system and the proportion that is retained in the lung:

- $> 10 \mu\text{m}$: retained in the upper airways
- $<10 >2.5 \mu\text{m}$: penetrate down to the bronchioles
- $<2.5 \mu\text{m}$: penetrate down to the alveoli, deposited in the lungs in a high proportion (80-90%)
- $<0.1 \mu\text{m}$: enter into the alveoli but a significant proportion are exhaled with the breath



Source: Theresa Knott, Wikimedia Commons (CC BY-SA 2.5)

DOI: 10.21037/amj.2020.03.04
DOI: 10.1007/s10661-006-9296-4

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Particulate Matter – Size vs Sedimentation

- Determines the spatial extent of pollution, the number of people exposed
- The bigger particulates will settle close to the source of pollution while smaller particulates will be settling at a slower rate or not at all and so will be carried away by the air currents to great distances.

PM > 10 μm : rapid sedimentation

PM 10 to 0.1 μm : settle at uniform rate; relative low diffusion in the air

PM 0.1 to 0.001 μm : do not settle; highly diffused to great distances

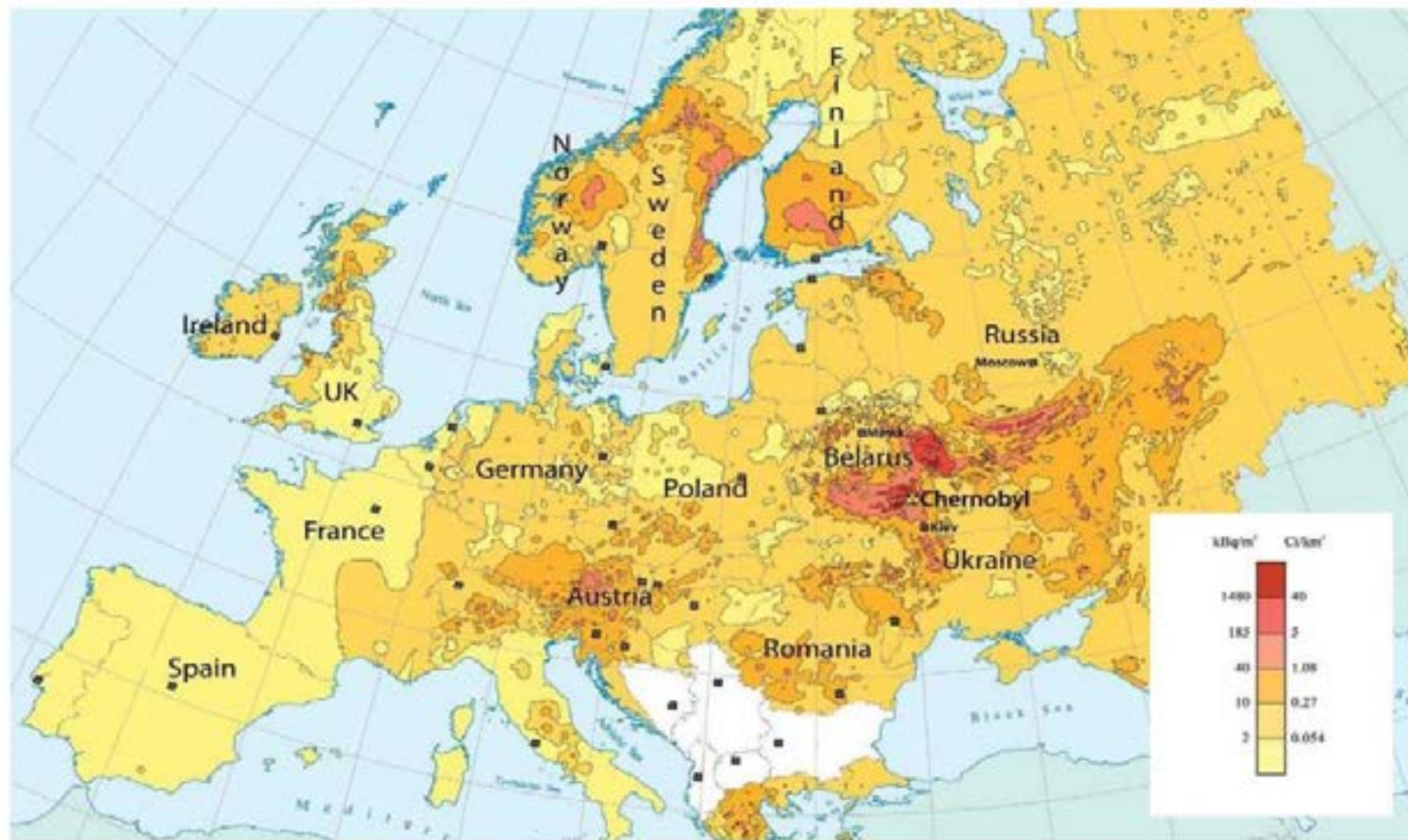
DOI: 10.21037/amj.2020.03.04
DOI: 10.1007/s10661-006-9296-4

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Particulate Matter – Size, Sedimentation, Propagation



Deposition of radioactive caesium-137 as measured two weeks after the radioactive emissions in 1986 from the Chernobyl nuclear plant (Ukraine).

<https://op.europa.eu/en/publication-detail/-/publication/110b15f7-4df8-49a0-856f-be8f681ae9fd> Accessed 19.02.2023.

Sources of fine inhalable particulates (PM_{2.5})

- Leading sources of PM_{2.5}: residential energy use, industry, power generation, wildfires.
- Total fire contribution to global mortality in 2017 was 4.1%.
- Wildfires - the single largest contributor to the PM_{2.5} disease burden in select regions throughout North America, Southeast Asia, and Africa.



Residential heating



Energy production



Industry



Road transportation



Wildfires

Source: Pixabay Free License

<https://www.nature.com/articles/s41467-021-23853-y> Accessed 02.02.2023.

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Particulate matter and climate change

- Black carbon - a component of particulate matter, including PM_{2.5}
- Black carbon - one of the largest contributors to global warming after CO₂
 - It warms the earth's atmosphere by absorbing sunlight, thereby accelerating the melting of snow and ice
 - When deposited on ice and snow, it causes local warming and further increases melting



Copsa Mica, Romania – carbon black factory

Source: FOTO: FORTEPAN / Voia, Wikimedia Commons (CC BY-SA 3.0)

www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/climate-impacts-of-air-pollution#:~:text=Black%20carbon%2C%20a%20component%20of,melting%20of%20snow%20and%20ice Accessed: 18.03.2023.

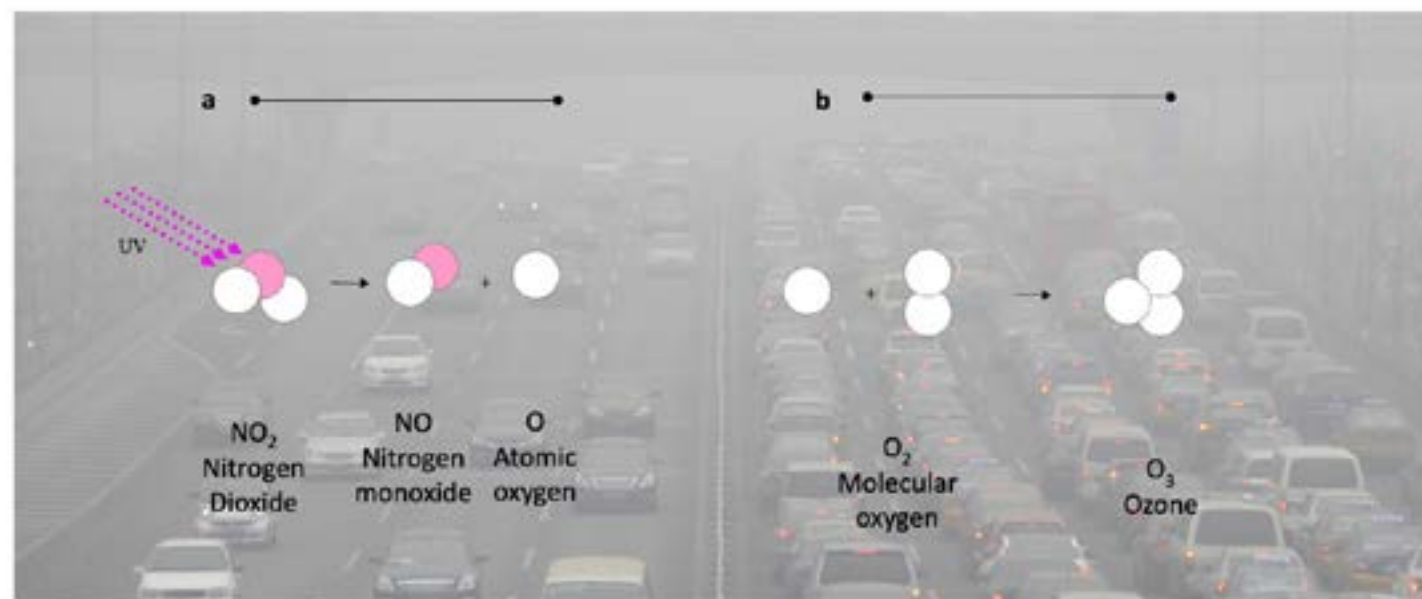
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Tropospheric Ozone (ground level ozone)

Secondary pollutant; urban areas, heavy car traffic, sunny days



Ozone is a gas composed of three atoms of oxygen. Ozone occurs both in the Earth's upper atmosphere and at ground level. Ozone can be good or bad, depending on where it is found.

Tropospheric, or ground level ozone, is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NO_x) and volatile organic compounds (VOC). This happens when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight. Called stratospheric ozone, good ozone occurs naturally in the upper atmosphere, where it forms a protective layer that shields us from the sun's harmful ultraviolet rays.

Ozone is most likely to reach unhealthy levels on hot sunny days in urban environments, but can still reach high levels during colder months. Ozone can also be transported long distances by wind, so even rural areas can experience high ozone levels.

People most at risk from breathing air containing ozone include people with asthma, children, older adults, and people who are active outdoors, especially outdoor workers. In addition, people with certain genetic characteristics, and people with reduced intake of certain nutrients, such as vitamins C and E, are at greater risk from ozone exposure.

Children are at greatest risk from exposure to ozone because their lungs are still developing

and they are more likely to be active outdoors when ozone levels are high, which increases their exposure. Children are also more likely than adults to have asthma.

Depending on the level of exposure, ozone can cause coughing and sore or scratchy throat. Make it more difficult to breathe deeply and vigorously and cause pain when taking a deep breath. Inflammation and damage the airways. Make the lungs more susceptible to infection. Aggravate lung diseases such as asthma, emphysema, and chronic bronchitis. Increase the frequency of asthma attacks.

Some of these effects have been found even in healthy people, but effects can be more serious in people with lung diseases such as asthma. They may lead to increased school absences, medication use, visits to doctors and emergency rooms, and hospital admissions. Some studies in locations with elevated concentrations also report associations of ozone with deaths from respiratory causes.

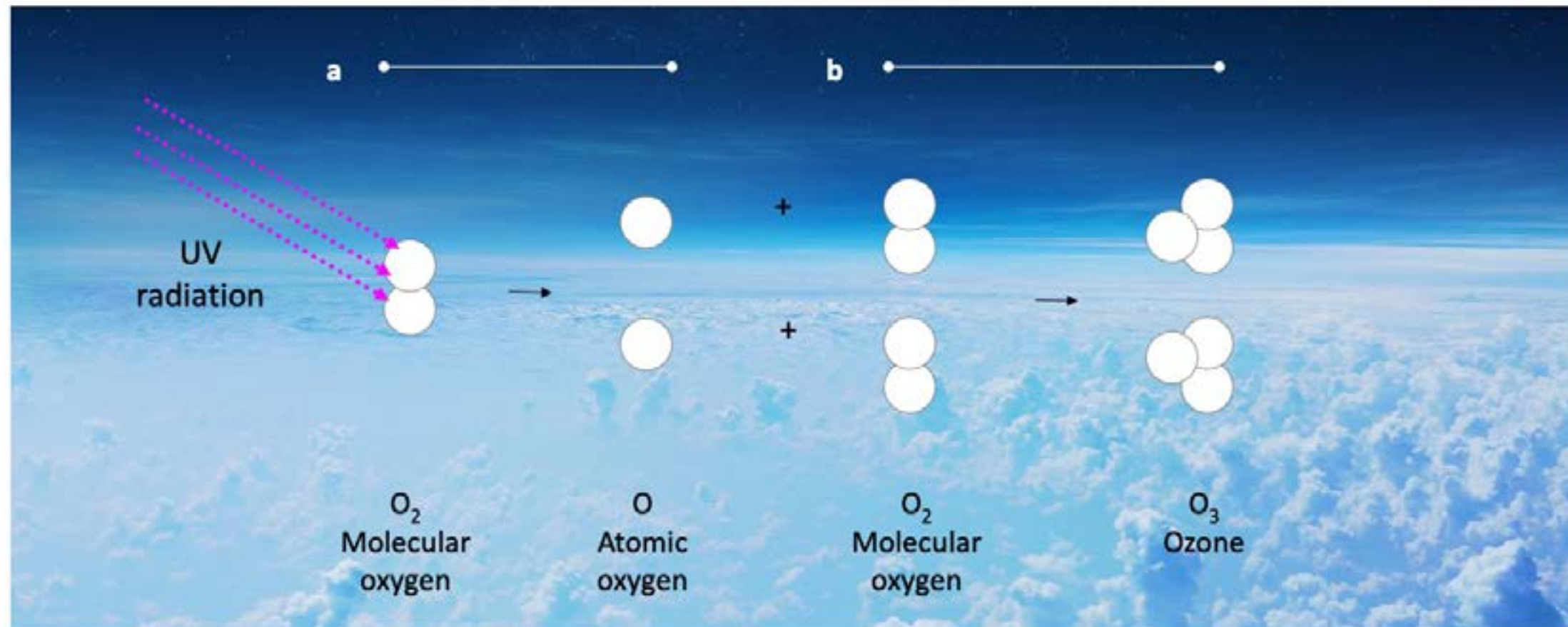
Long-term exposure to ozone is linked to aggravation of asthma, and is likely to be one of many causes of asthma development.

→ <https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution>

Accessed: 13.02.2023

Stratospheric ozone (15-35 km altitude)

Protective role - filters cosmic UV radiation (most of UVC and large part of UVB)



Source: Pixabay Free License

<https://www.epa.gov/ozone-pollution-and-your-patients-health/what-ozone> Accessed: 23.03.2023.

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Stratospheric ozone, called good ozone, occurs naturally in the upper atmosphere, where it forms a protective layer that shields us from the sun's harmful ultraviolet rays.

Stratospheric ozone levels affect climate systems and alter atmospheric circulation in both the troposphere and stratosphere.

The emission of human-made ozone-depleting substances, commonly used in refrigeration and air conditioning, foam products, aerosols, solvents, and for fire suppression, has been damaging the ozone layer.

Stratospheric ozone depletion

Brewer-Dobson atmospheric circulation pushes equatorial tropospheric air upward to the stratosphere and transport it to the poles.

Unique geographical, meteorological, and chemical factors combine at the poles and results in seasonal stratospheric ozone depletion.



The use of aerosols (e.g., chlorofluorocarbons and hydrochlorofluorocarbons) contributed to increasing UV radiation exposure and skin cancer Australia – annual UV radiation level increase of 2% to 6% since 1990 2011 - large hole in ozone layer in the Northern Hemisphere over the Arctic 60% increase in UV radiation exposure at the ground level in the area.

The good news is this hole is diminishing. Through international actions and regulations to phase-out these substances, the ozone layer is healing and should fully recover by about 2065.

→ <https://www.epa.gov/ozone-layer-protection>

↘ Accessed: 13.02.2023

Climate change - the largest threat to stratospheric ozone recovery

Ozone depletion and climate change are interrelated in a complex and bidirectional way

Chemical reactions at the surfaces of polar stratospheric clouds, significantly increase the concentration of reactive halogen gases.

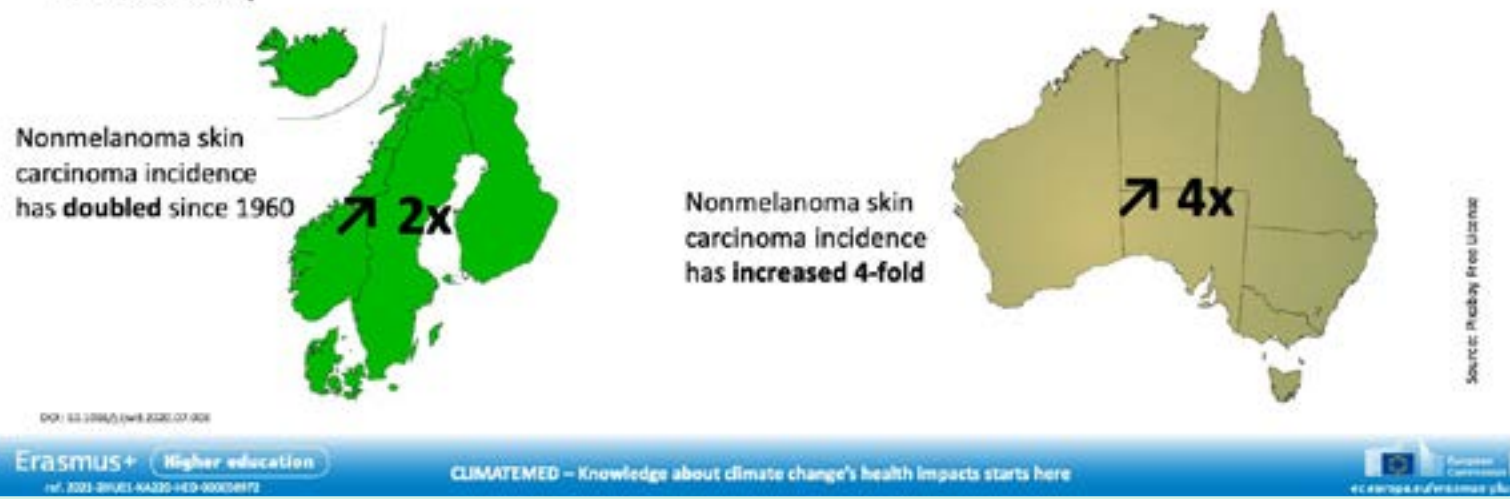
During winter, polar stratospheric clouds form in the atmosphere over Antarctica and the Arctic during winter (1 to 2 months over the Arctic, up to 5 months over Antarctica).

→ Antarctic stratospheric ozone depletion

- disrupts the patterns in tropospheric circulation, temperature, and precipitation
- is a dominant driver of climate change in the Southern Hemisphere and the tropics
- influenced El Nino southern oscillation events
- shifted the North Atlantic jet stream, resulting in temperature and precipitation changes in the Northern Hemisphere

Ultraviolet radiation and skin cancers

- Skin cancer - most common cancer worldwide
- Cutaneous malignant melanoma and nonmelanoma skin carcinoma incidence rates have increases substantially during the last part of the 20th century
- UV radiation – the primary driver in the pathogenesis of skin cancer (although the etiology is multifactorial)



Extensive data in the literature linking increased exposure to UV radiation to increased incidence of melanoma, squamous cell and basal cell cancers

Squamous cell and basal cell cancer - globally, since 2007 33% increase in cases; 7.7 million cases; 65000 deaths

Melanoma attributed to UV radiation, in 2012, globally 230 000 incident cases; 55 000 deaths

→ DOI: 10.1016/S1470-2045(20)30448-4

Montreal Protocol (1987) succeeded in reducing ozone layer depletion and incidence of skin cancers (by 2 million until 2030)

International environmental policy mandated the incremental phasing out of ozone-depleting substances (ratified by every nation)

Through these measures and regulations millions of skin cancers could be prevented worldwide.

Increases in skin cancer incidence are still expected before the full recovery of the stratospheric ozone layer

- The effect of greenhouse gases on the ozone layer and associated exposure to UV radiation varies across the globe
- Increased UV exposure close to the equator
- Increased UV exposure at higher altitudes
- Risk is influenced by biological factors
- Risk increased in fair-skinned people
- Risk is influence by behavioral factors
- Sun-centric culture (emphasis on outdoor recreation) may contribute to excessive exposure

→ DOI: 10.1016/S1470-2045(20)30448-4

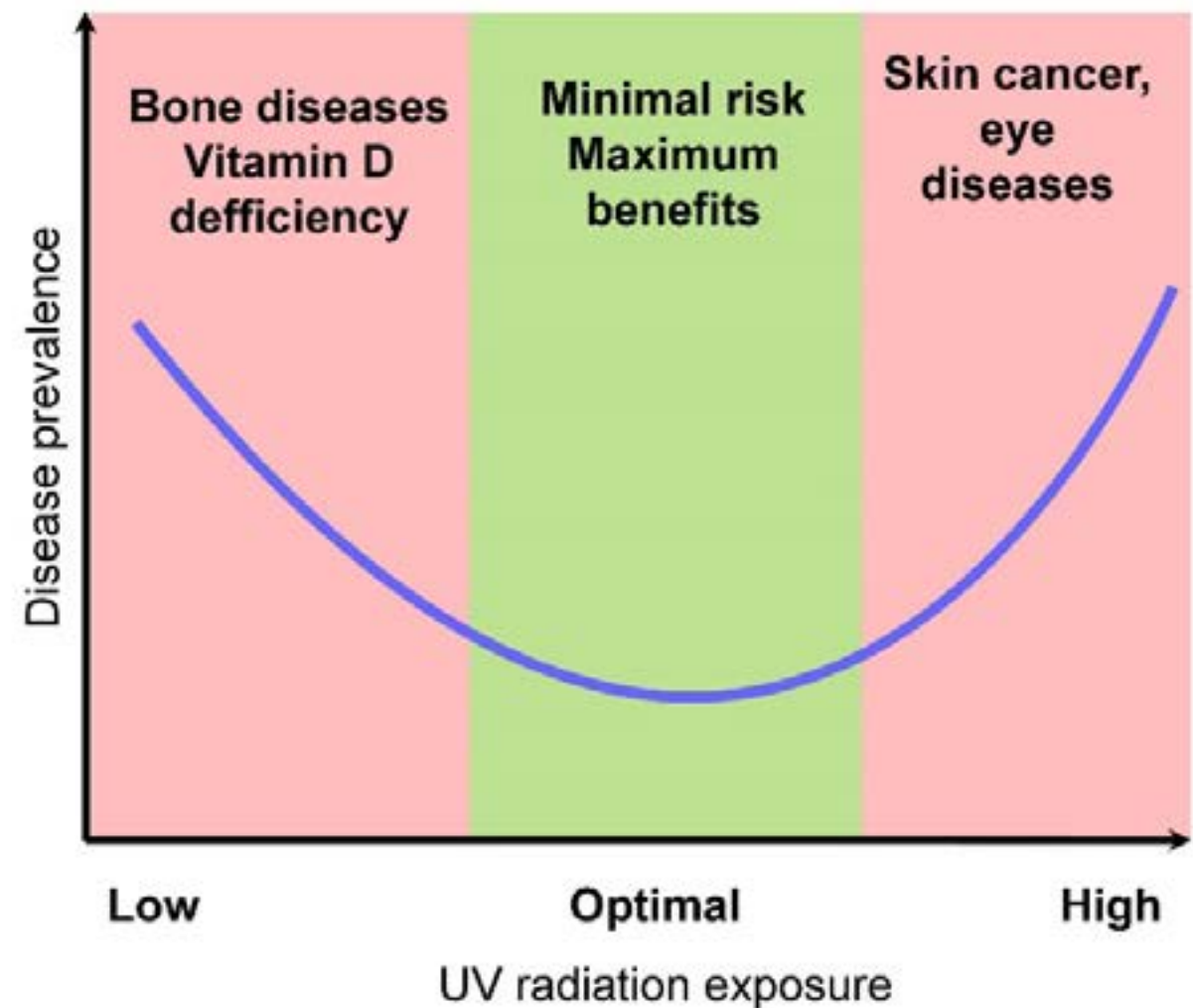
→ DOI: 10.1016/j.ijwd.2020.07.003

→ DOI: 10.1016/S1470-2045(20)30448-4

→ DOI: 10.1016/j.ijwd.2020.07.003

Ultraviolet radiation and skin cancers

- Vitamin D, synthesized in the skin-positive health effects (musculoskeletal health, calcium metabolism, and immune function)
- Diverging opinions regarding balance point between risk and benefits of exposure to UV radiation



Cancer related to disruptions in food and water supply

Climate change – impact on the quality and quantity of food production through increasing temperatures, flooding, drought, extreme weather events, higher ground-level ozone, interference with pollinator insects, rising sea levels.



By 2050, an estimated 534,000 deaths worldwide are expected due to climate-related issues, including cancer linked to changes in food supply.

Exposure to industrial toxicants

Environmental toxicants are likely to increase with increased industrialisation and chemical production independent of climate change.

Climate change may further increase exposure to environmental toxins.



Source: <https://shorturl.at/Kjgnf>

DOI: 10.1016/S1470-2045(20)30448-4

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Modelling studies on glacial meltwater (Alaska, Swiss Alps) - pollutants can accumulate in the local fish supply and may increase cancer risk among local populations with high fish intake.

Wildfires may increase exposure to toxic chemicals through air pollution and contamination of ground water (California, USA, drinking and ground-water sources higher concentrations of benzene after wildfires).

Flooding of toxic waste storage sites - increased risk of exposure to toxic chemicals.

→ DOI: 10.1016/S1470-2045(20)30448-4

Mycotoxins

- Mycotoxins - naturally occurring toxins produced by certain molds (fungi)
- Fungi of the genus *Aspergillus*, *Fusarium* and *Penicillium*
- Aflatoxins (AF) - produced by *Aspergillus flavus*
- *Aspergillus* - grow in soil, decaying vegetation, hay, and grains
- Aflatoxin B1 (AFB1) - the most potent known natural carcinogen
- Other important mycotoxins: Fumonisin B1 (FB1) and Ochratoxin A (OTA)



Crops frequently affected (*Aspergillus* spp.): cereals (corn, sorghum, wheat and rice), oilseeds (soybean, peanut, sunflower and cotton seeds), spices (chili peppers, black pepper, coriander, turmeric and ginger) and tree nuts (pistachio, almond, walnut, coconut and Brazil nut). The toxins can also be found in the milk of animals that are fed contaminated feed, in the form of aflatoxin M1.

FAO estimations: 25% of global samples contaminated

→ DOI: 10.3390/toxins13060399

→ www.who.int/news-room/fact-sheets/detail/mycotoxins

↘ Accessed: 25.02.2023.

→ DOI: 10.1080/10408398.2019.1658570

Climate (temperature, precipitation, and atmospheric CO₂ concentration) represents the key driving force of agricultural ecosystems

Climate changes may significantly impact fungal colonization and mycotoxin production.

Climate changes could lead to unexpected increases/reductions in mycotoxin contamination of crops in the field and post-harvest.

Climate change could result in changes in the fungal biodiversity and emergence of new diseases.

→ DOI: 10.3390/microorganisms8101496

1960s - a new turkey disease with high mortality identified in England

The turkey "X" disease

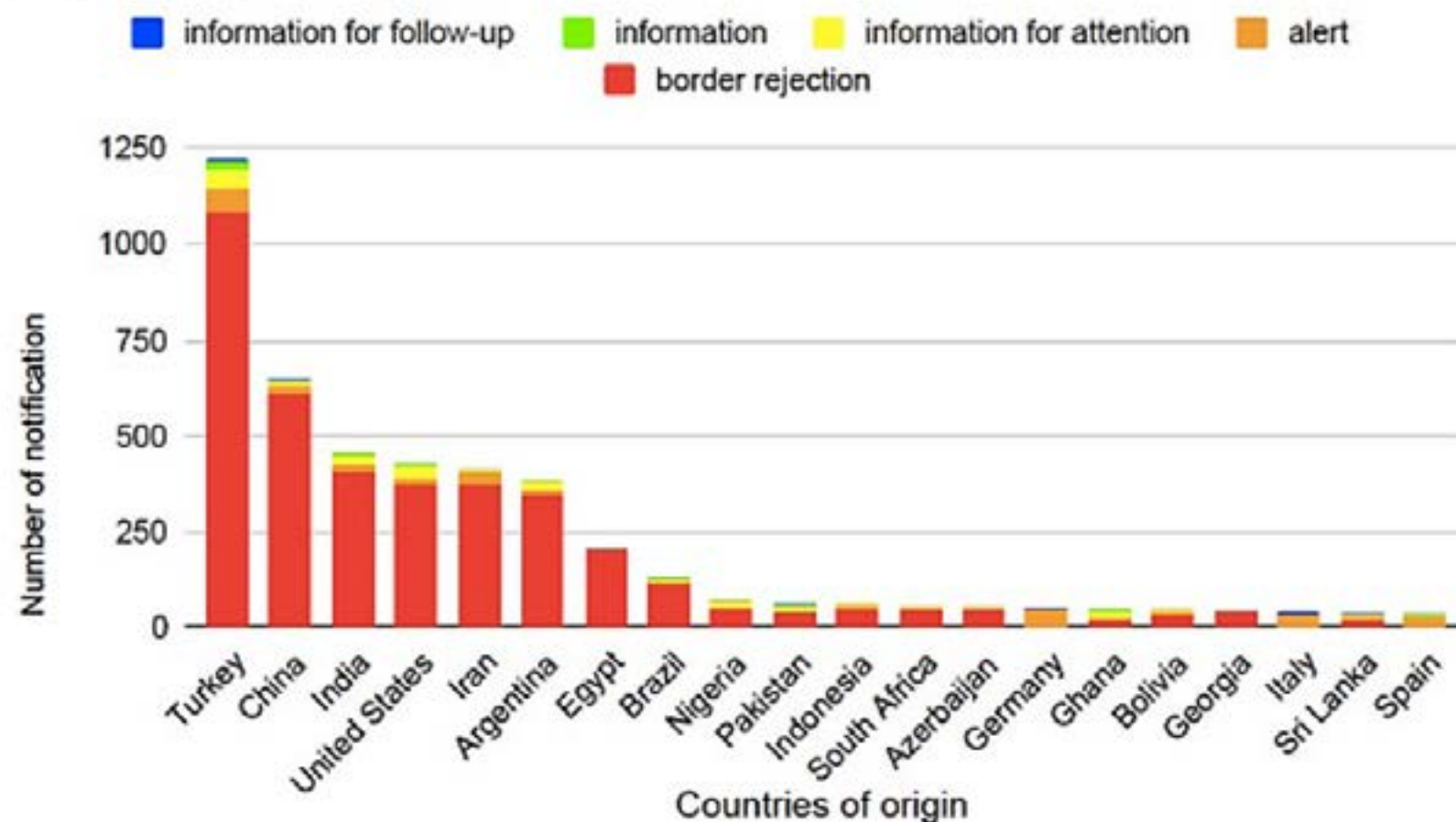
100,000 turkeys died after being fed with contaminated Brazilian groundnut meal on a poultry farm in London.

William Percy Blount - veterinary scientist developed an effective poultry disease diagnostic service

Mycotoxins enter the food chain as a result of infection of crops before or after harvest

Exposure to mycotoxins typically by eating contaminated foods or from animals that are fed contaminated feed

Aflatoxin-related notifications - EU



Countries of origin for aflatoxin-related notifications in food based on the European Union Rapid Alert System for Food and Feed (RASFF) database from 1st January 2009 until 27th June 2019

DOI: 10.3389/fmicb.2019.02908

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Mycotoxin effects on human health

	Aflatoxin B ₁	Ochratoxin A	Patulin	Fumonisin	Trichothecenes	Zearalenone	Citrinin	Stenogramycin
Carcinogenic	✓	✓	✓	✓	✓	✓	✓	✓
Genotoxic	✓	✓	✓	✓	✓	✓	✓	✓
Hepatotoxic	✓	✓	✓	✓	✓	✓	✓	✓
Immunotoxic	✓	✓	✓	✓	✓	✓	✓	✓
Nephrotoxic	✓	✓	✓	✓	✓	✓	✓	✓
Neurotoxic	✓	✓	✓	✓	✓	✓	✓	✓
Oestrogenic	✓	✓	✓	✓	✓	✓	✓	✓
Teratogenic	✓	✓	✓	✓	✓	✓	✓	✓

Based on the IARC Monographs classification of carcinogenic hazard:

● Group 1: Carcinogenic to humans
 ● Group 2B: Possibly carcinogenic to humans
 ● Group 3: Not classifiable as to its carcinogenicity to humans

Controlling and minimizing the risk from mycotoxins

Good agricultural practices effectively control A. flavus infection in the field:

- Timely planting
- Providing adequate plant nutrition
- Controlling weeds
- Crop rotation

Efficient drying of commodities and maintenance of the dry state

Proper storage - effective measure against mold growth and the production of mycotoxins (mold does not grow in properly dried and stored foods)

Disposal of contaminated stocks

ISBN: 9780124114715, 45-49.

Effects: hepatotoxic, carcinogenic, teratogenic, immunosuppressive, nephrotoxic

Mycotoxicoses can manifest as acute or chronic intoxications

Acute mycotoxicoses caused by exposure to high amounts of mycotoxins

In the past - common even in moderate temperature zones, causing epidemics that devastated entire regions (during famines, moldy foods)

Nowadays, mostly in tropical countries (Africa, Asia) with equal severity and high mortality

Symptoms appear quickly and, if exposure continues, the outcome may be fatal.

Chronic exposure to AF has been associated with an increased risk of cirrhosis and liver cancer.

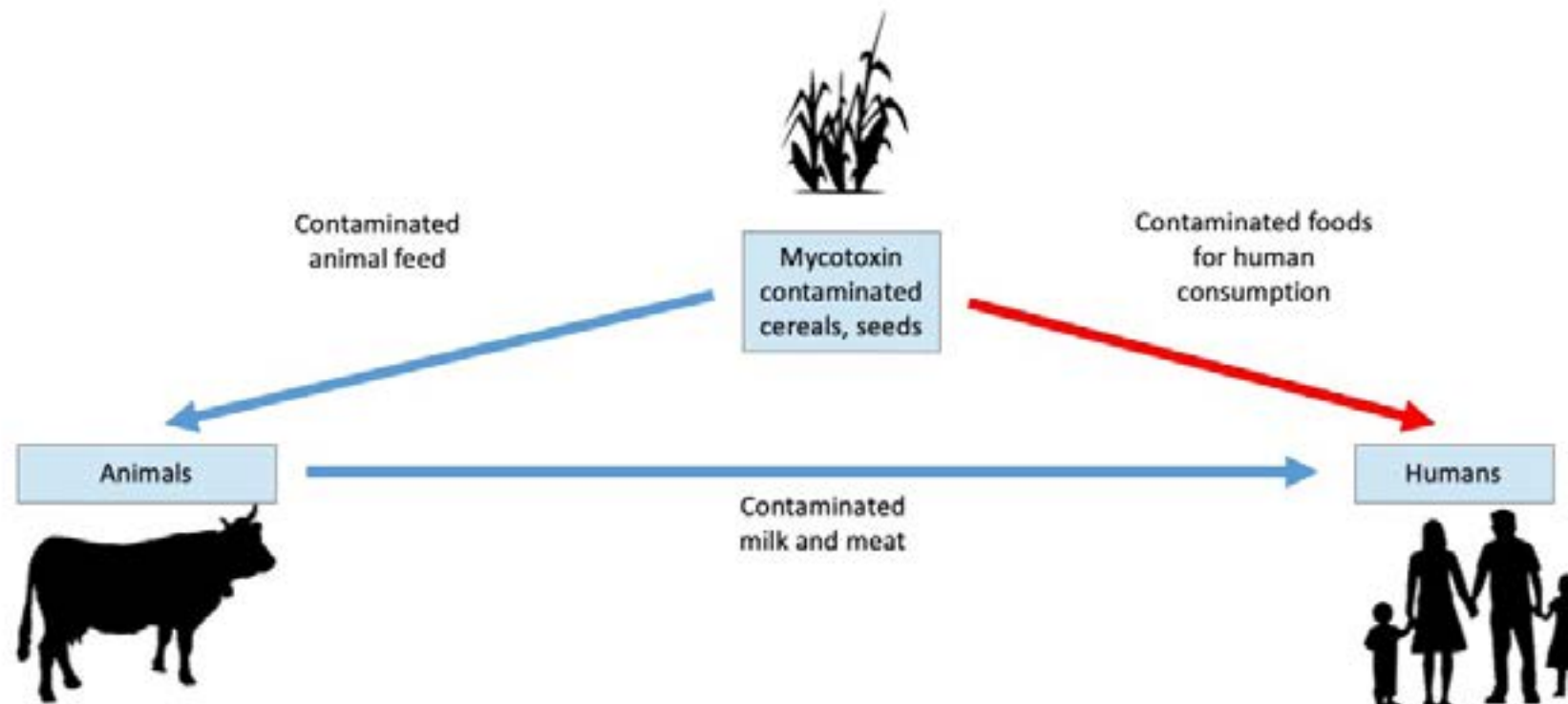
About 25,000-150,000 cases of liver cancer are attributed annually worldwide to aflatoxin exposure.

Aflatoxin may play a causative role in up to 1/3 of all global liver cancer cases.

Most cases occur in sub-Saharan Africa, Southeast Asia, and China, where populations suffer from both high HBV prevalence and largely uncontrolled aflatoxin exposure in food.

Indirect exposure of human population

Contaminated milk consumption by humans can increase the risk of liver cancer



DOI: 10.3389/fmicb.2016.02170
DOI: 10.4103/0019-557X.96985

Source: pixabay.com (free images)

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Humans may be exposed indirectly by consuming food products from animals fed aflatoxin-contaminated feed

- Milk
- Egg
- Meat

Epidemiological studies - contaminated milk consumption increases the risk of liver cancer in humans

Aflatoxins – heat resistant; decompose only > 200 – 300°C

Pasteurization or boiling of milk can not protect humans against AF exposure

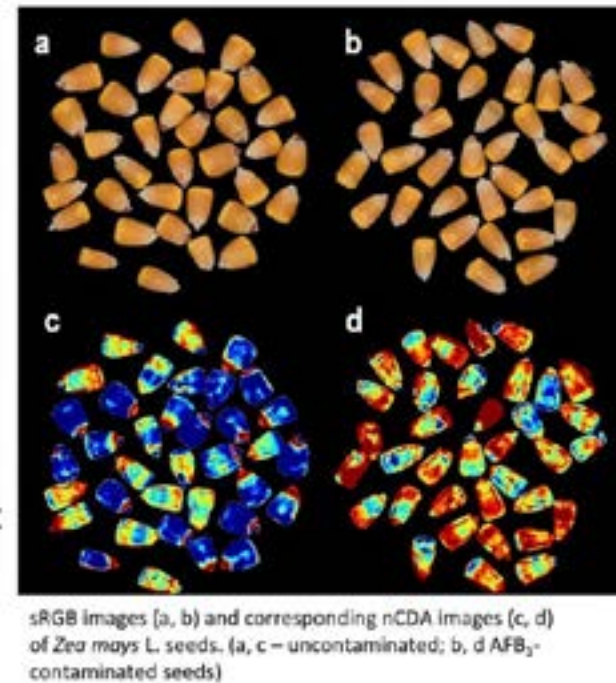
- DOI: 10.3389/fmicb.2016.02170;
- DOI: 10.4103/0019-557X.96985

Mycotoxin detection methods

Most frequently used methods:

- High performance liquid chromatography (HPLC)
- Liquid chromatography mass spectroscopy (LCMS)
- Enzyme linked immune-sorbent assay (ELISA)

Biosensors and immunoassays developed to detect ultra traces of aflatoxins



Biological control of mycotoxins

Atoxigenic *A. flavus* strains are used to displace the toxigenic populations of the fungus

A. flavus strains are approved by the US EPA and used for the prevention of aflatoxin in peanuts, corn, and cottonseed

Other bacteria

- *Bacillus subtilis*
- *Lactobacillus* spp.
- *Pseudomonas* spp.
- *Ralstonia* spp.
- *Burkholderia* spp.

→ DOI: 10.3389/fmicb.2016.02170

Aflatoxins detected and identified based on their absorption and emission spectra

Some aflatoxins exhibit blue fluorescence, others, green fluorescence under UV irradiation

Inactivation / extraction of mycotoxins

Degradation treatments

- Some aflatoxins are removed by ozone treatment

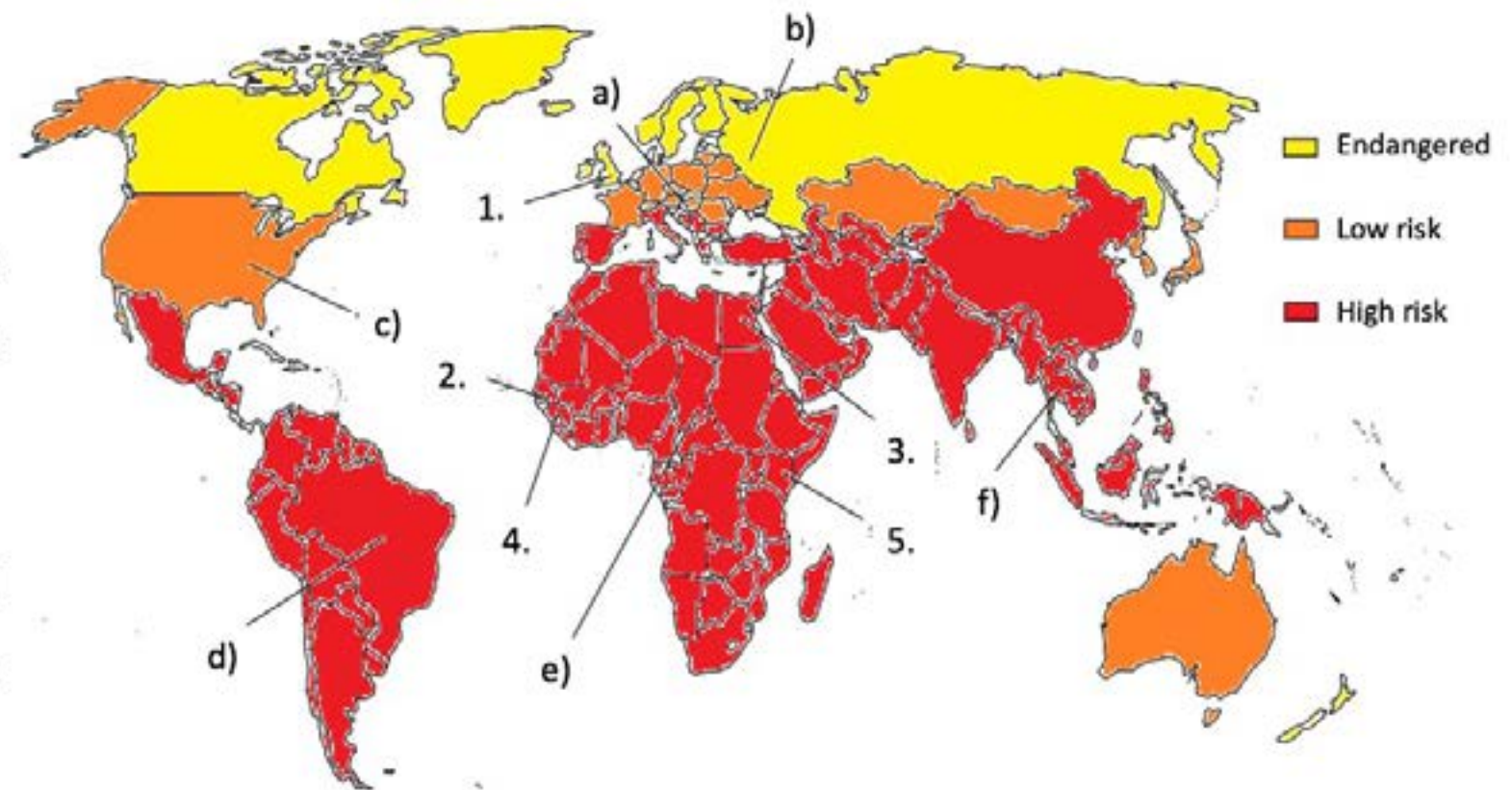
Microbial and enzymatic degradation methods – preferred due to their eco-friendly nature

- ex. *Flavobacterium aurantiacum*,
- *Rhodococcus* species;
- fungi such as *Pleurotus ostreatus* transform AFB₁ into less toxic forms

Mycotoxin formation and climate change

Due to climate change
Aspergillus species are
moving constantly north

In tropical countries, mold
related challenges may be
exacerbated



ISBN: 9780124114715, 45-49.
DOI: 10.3389/fmicb.2019.02908

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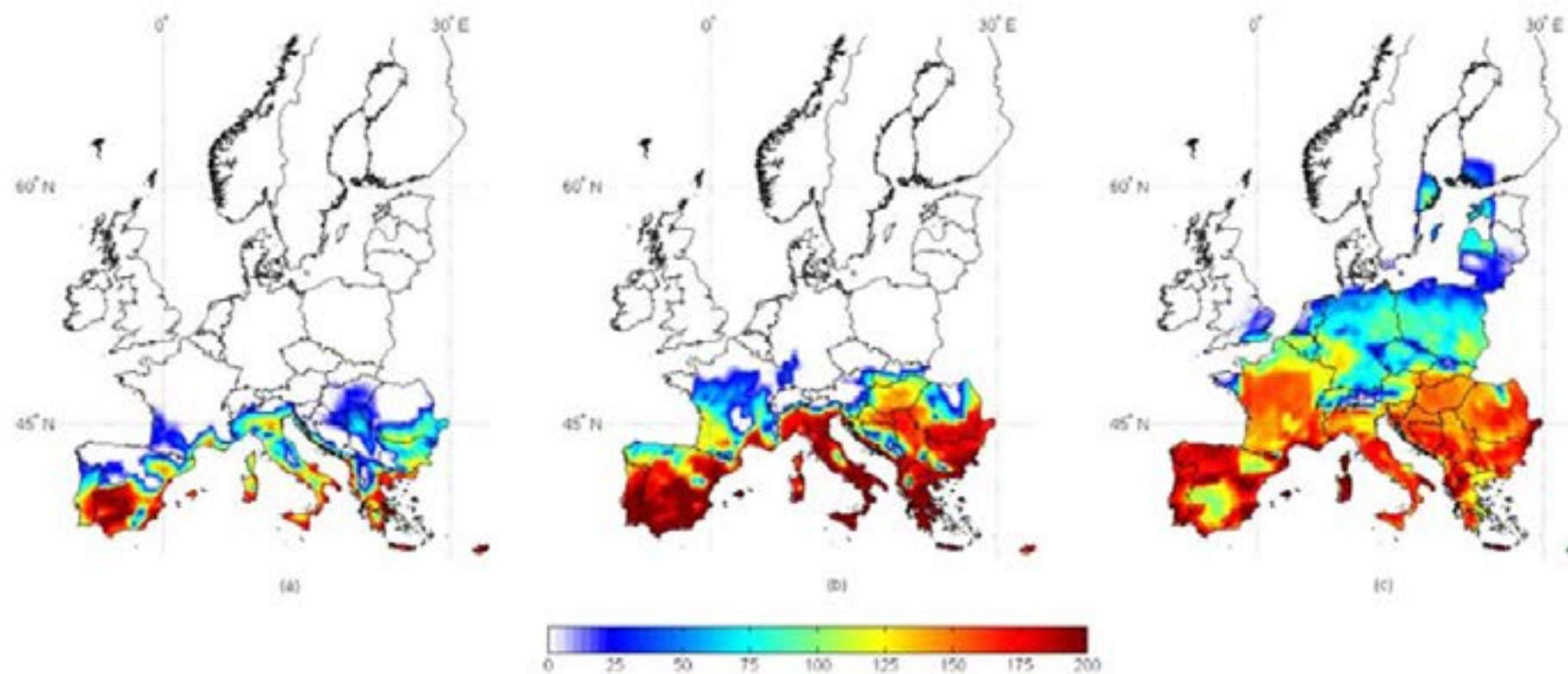
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Environmental conditions promoting mycotoxin
formation: moisture and high temperature

Mycotoxicoses – much more frequent in tropical
than in moderate regions

Mycotoxins and climate change scenarios

An increase from a low to a medium probability of aflatoxin contamination is found under the + 2°C scenario



DOI: 10.1038/srep24328

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Certain fungi may disappear, while appearing in new regions previously not at risk

Modelling study – marked increase of aflatoxins contamination risk of corn crops in Northern Italy and Eastern Europe in case of +2°C and +5°C scenario

Under the current climatic conditions, European countries in which maize cultivation is common, i.e. in Romania, France, Hungary and north-east Italy (in total accounting for 60% of the total production in 2013 for the 28 EU Member States, FAOStat, 2013), show a low probability of aflatoxin occurrence.

Take home messages

- Climate change control requires integrated, sustained, multilevel interventions but reaching consensus among stakeholders with divergent interest is difficult because of the complexity and technical character of the evidence.
- Science/evidence is not enough for concerted action.
- Effective communication is essential.

Must-Read Materials

- Hiatt RA, Beyeler N. Cancer and climate change. *Lancet Oncol.* 2020 Nov;21(11):e519-e527. doi: 10.1016/S1470-2045(20)30448-4
- Vineis P, Huybrechts I, Millett C, Weiderpass E. Climate change and cancer: converging policies. *Mol Oncol.* 2021 Mar;15(3):764-769. doi: 10.1002/1878-0261.12781
- Parker ER. The influence of climate change on skin cancer incidence - A review of the evidence. *Int J Womens Dermatol.* 2020 Jul 17;7(1):17-27. doi: 10.1016/j.ijwd.2020.07.003.
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- Kumar P, Mahato DK, Kamle M, Mohanta TK, Kang SG. Aflatoxins: A Global Concern for Food Safety, Human Health and Their Management. *Front Microbiol.* 2017 Jan 17;7:2170. doi: 10.3389/fmicb.2016.02170.

Test your knowledge

- What are the principal mechanisms linking climate change to increased cancer incidence?
- What type of cancers are possibly associated with climate change?
- How can climate change result in increased exposure to UV radiation and ultimately increased incidence of skin cancers?
- How can climate change contribute to mycotoxin contamination of food products?
- What pathologies are causally related to exposure to mycotoxins?
- What are the food crops most frequently affected by mycotoxin contamination?
- What are the basic strategies to control and mitigate the risk of mycotoxin exposure?

Thank you for your attention!

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National Public Health Center – Budapest, Hungary



University College Cork – National University of Ireland – Cork, Ireland



Universitatea de Medicina, Farmacie, Stiinte si Tehnologie
George Emil Palade din Tirgu Mures – Tirgu Mures Romania

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Impact of wildfires, droughts, extreme weather events

Introduction

- Wildfires, droughts, and extreme weather events are all direct consequences of climate change. These events can have wide-ranging impacts on the environment, economy, and human health.
- Extreme weather events, such as floods, hurricanes, and tornados, can cause extensive damage to infrastructure, homes, and businesses, leading to economic losses and disruption. In addition, these events can also lead to injuries and fatalities.
- The direct effects of extreme weather events on human health can include exposure to the elements, impact on mental health, injuries during escape attempts, and even deaths caused by the weather event. These events continue to cause significant human morbidity and mortality and adversely affect mental health and well-being.
- Climate change has caused changes in the frequency, intensity and geographic distribution of extreme events and will continue to drive change in the future.

Wildfire

Definition: a wildfire is an unplanned fire that burns in a natural area such as a forest, grassland, or prairie. Wildfires are often caused by human activity or a natural phenomenon such as lightning, and they can happen at any time or anywhere.



Source: https://www.who.int/health-topics/wildfires#tab=tab_1

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The risk of wildfires increases in extremely dry conditions, such as drought, and during high winds.

In 50% of wildfires recorded, it is not known how they started.

Wildfires can disrupt transportation, communications, power and gas services, and water supply. They also lead to a deterioration of the air quality, and loss of property, crops, resources, animals and people.

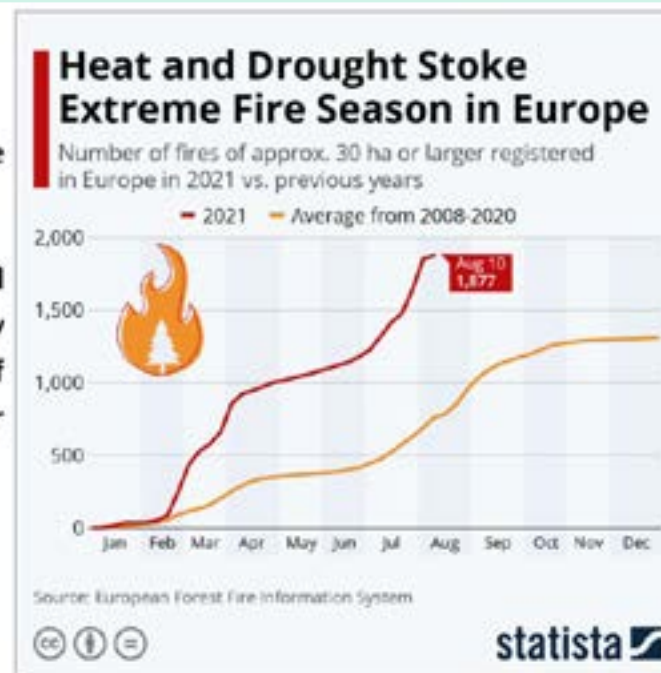
Wildfire

The size and frequency of wildfires are growing due to climate change.

Hotter and drier conditions are drying out ecosystems and increasing the risk of wildfires. Wildfires also simultaneously impact weather and the climate by releasing large quantities of carbon dioxide, carbon monoxide and fine particulate matter into the atmosphere.

Wildfire can cause a range of health issues including

- burning damages and other injuries;
- detrimental effects on mental health and psychosocial well-being;
- smoke pollution.



Health hazards of wildfire – impacts on mental health

→ The psychological impacts of wildfires can be long-lasting and far-reaching. People may experience

- depression,
- anxiety,
- post-traumatic stress disorder, and
- other mental health issues due to their experiences with the fires.

→ People who have experienced wildfires may experience trauma-related symptoms such as

- difficulty sleeping,
- flashbacks,
- intrusive thoughts, and hypervigilance.

→ The fear of future wildfires and their potential destruction can be a source of ongoing distress. The disruption of daily life, loss of community and social networks, and financial strain can also cause mental health issues.

Health hazards of wildfire - burning damages and other injuries

→ The most common injury caused by wildfires is burns. Most of the cases, these injuries are second- or third-degree burns. Due to the extraordinary circumstances of the injury, patients with wildfire burns may need psychological services and support groups in addition to professional care for their burns.

→ The other frequent injuries in addition the burns are

- eye, nose, throat and lung irritation
- decreased lung function, including coughing and wheezing

- pulmonary inflammation, bronchitis, exacerbations of asthma, and other lung diseases
- exacerbation of cardiovascular diseases, such as heart failure

→ Wildfires also release significant amounts of mercury into the air, which can lead to impairment of speech, hearing and walking, muscle weakness and vision problems for people of all ages.

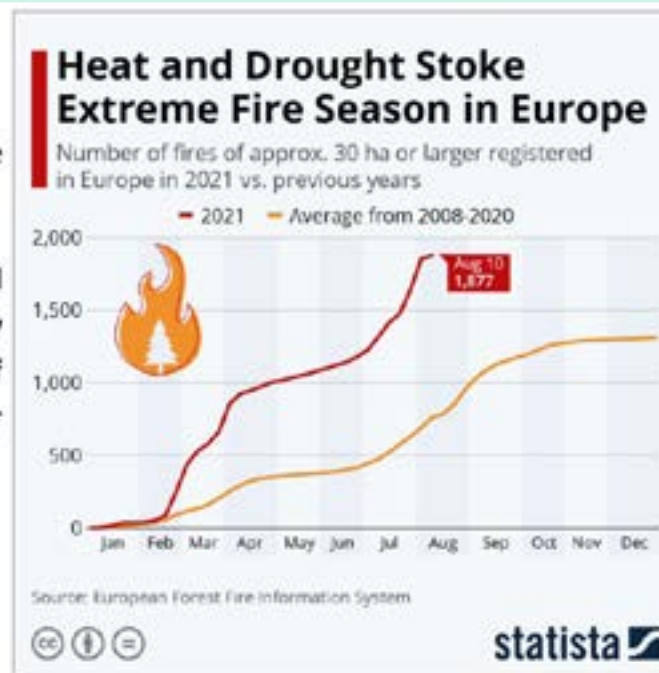
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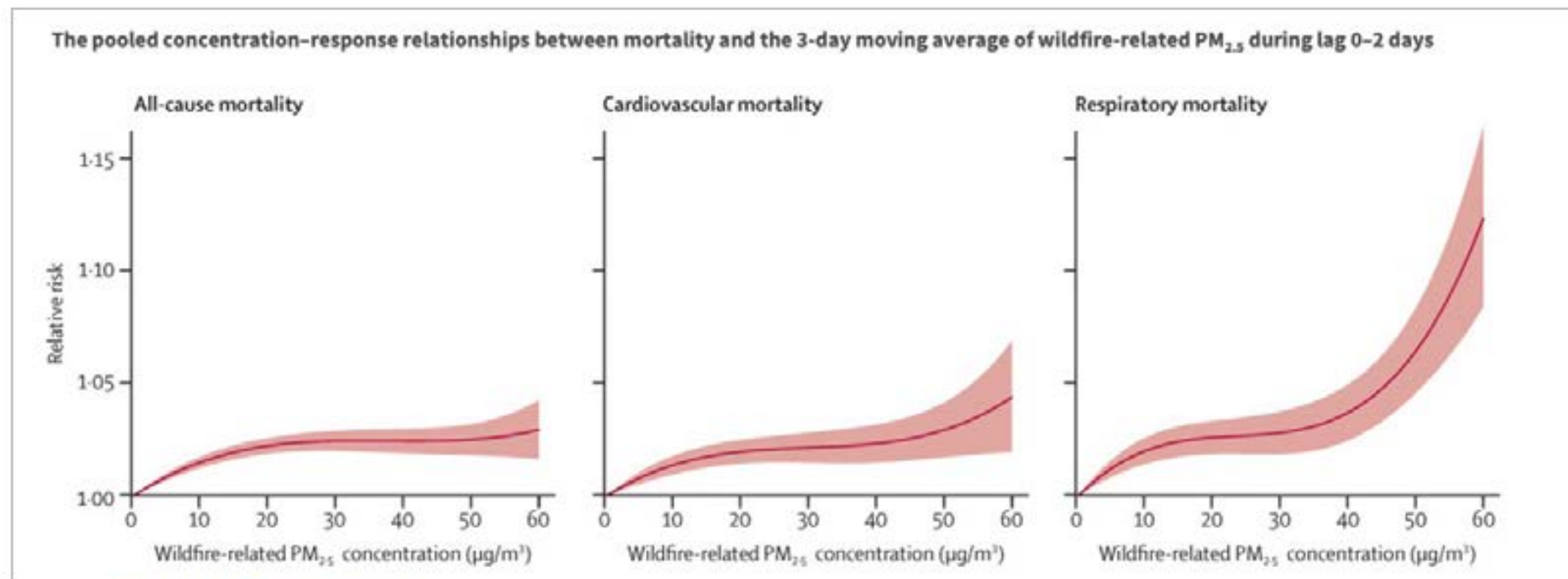
Health hazards of wildfire - smoke pollution

→ Wildfire smoke is a complex mixture of particulate matter (PM) and gaseous pollutants. Among the various air pollutants emitted by wildfires, fine particulate matter (PM_{2.5}) is of great concern, as particles in this size range enter into the lungs and reach the alveoli where the small particles can translocate through the alveolar epithelium and enter the circulation.

→ Compared with PM_{2.5} from urban sources, wildfire-related PM_{2.5} tends to be more toxic due to its chemical composition and smaller particle size, and is often accompanied by co-exposure to other harmful environmental factors, particularly high temperatures.

Health hazards of wildfire – smoke pollution

Chen and colleagues analysed mortality data for 750 cities in 43 countries in 2021 and found that wildfire smoke pollution increases all-cause, cardiovascular and respiratory mortality. Thus, wildfire smoke exposure can be interpreted as a complex mortality factor.



Chen et al. 2021 The Lancet [https://doi.org/10.1016/S2542-5198\(21\)00260-X](https://doi.org/10.1016/S2542-5198(21)00260-X)

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Health hazards of wildfire – smoke pollution

Moscow, Russia, Yasenevo, Aivazovskogo street.

Left – 17 June 2010, 20:22

Right – 7 August 2010, 17:05



Source: Axyraraa - Own work, CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=11114108>

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Drought

Drought is a prolonged dry period in the natural climate cycle that can occur anywhere in the world. It is a slow-onset disaster characterized by the lack of precipitation, resulting in a water shortage. Drought can have a serious impact on health, agriculture, economies, energy and the environment.

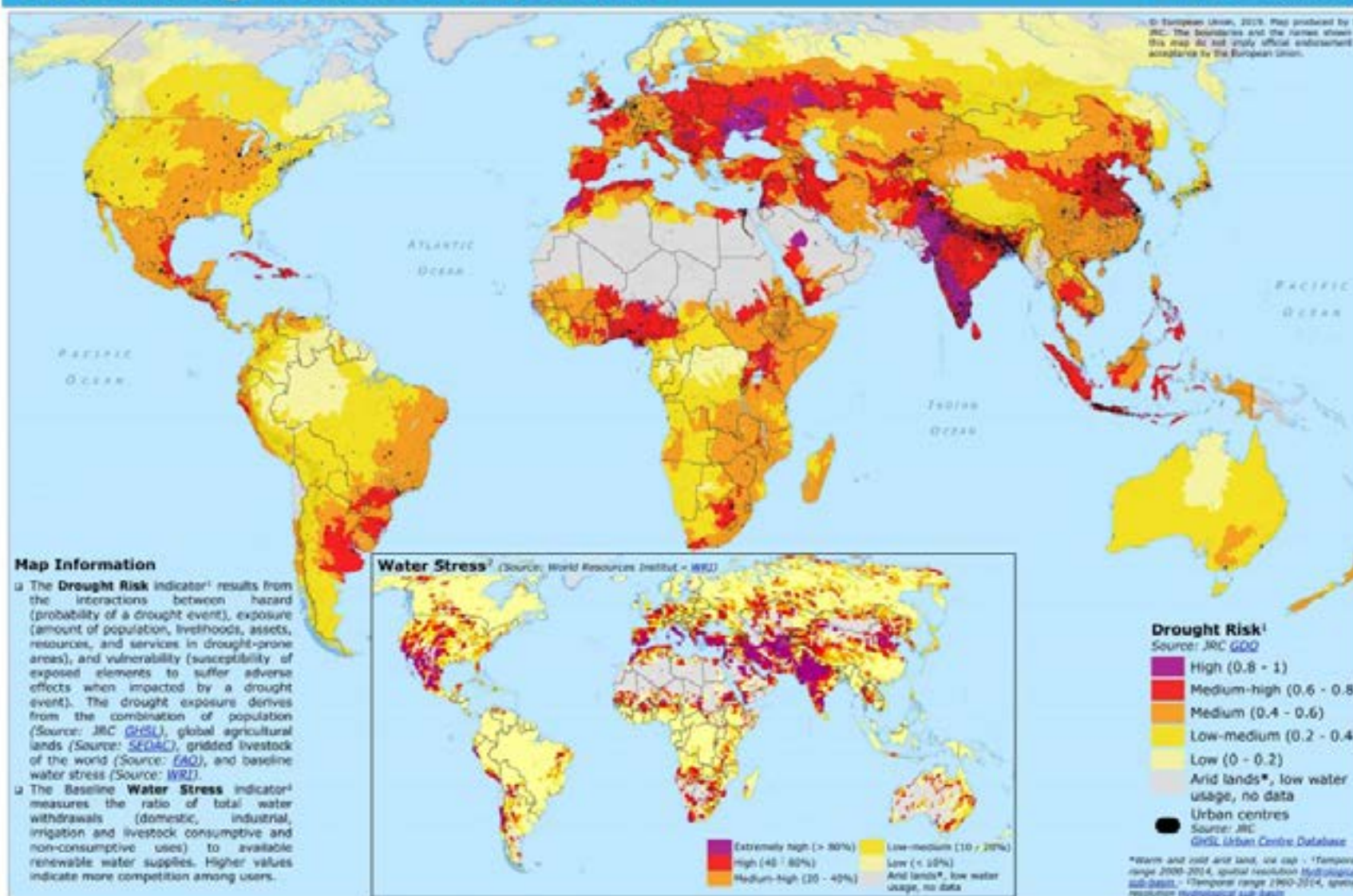


- An estimated 55 million people globally are affected by droughts every year, and they are the most serious hazard to livestock and crops in nearly every part of the world. Drought threatens people's livelihoods, increases the risk of disease and death, and fuels mass migration.
- Water scarcity impacts 40% of the world's population, and as many as 700 million people are at risk of being displaced as a result of drought by 2030.

- Rising temperatures caused by climate change are making already dry regions drier and wet regions wetter. In dry regions, this means that when temperatures rise, water evaporates more quickly, and thus increases the risk of drought or prolongs periods of drought.
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Global Drought Risk and Water Stress



Drought – health impacts

Drought may have acute and chronic health effects, including:

- malnutrition due to the decreased availability of food, including micronutrient deficiency, such as iron-deficiency anaemia;
- increased risk of infectious diseases, such as cholera, diarrhea, and pneumonia, due to acute malnutrition, lack of water and sanitation, and displacement;
- psycho-social stress and mental health disorders;
- disruption of local health services due to a lack of water supplies, loss of buying power, migration and/or health workers being forced to leave local areas.

https://www.who.int/health-topics/drought?gclid=Cj0KCQjwu-IGBNCuARsAPzUf3i7nK3NucdP5oh5gcw9gdnKGWbYlF4UusHFc43gM67Td9BQaAbiEALw_wcB#tab=tab_1

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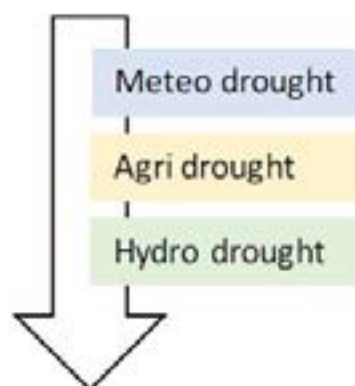
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→ Drought causes water and food shortages, which may impact the affected population's life chances and increase the risk of disease and death.

→ Severe drought can also affect air quality by making wildfires and dust storms more likely, increasing health risk in people already impacted by lung diseases, like asthma or chronic obstructive pulmonary disease (COPD), or with heart disease.

Drought-related health challenges and potential adaptation strategies



Pathways / controls	Potential interventions
Atmospheric pollution	Use of relationships between atmospheric patterns and weather extremes for prediction and early warning.
Occurrence of wildfires	Land use control including soil water content monitoring.
Food insecurity	Local interventions focused on increasing the nutritional diversity of agricultural systems.
Social isolation, altered community structures	Strengthening of community support and resources.
Impaired sanitation and hygiene	Construction/capacity increase/maintenance of water supply & sewage systems.
Water contamination	Educational activities on water saving and monitoring + systematic case reporting and communication.
Availability of aquatic habitats suitable for disease vectors	Wetland management (and surveillance systems for large-scale data collection).

Beltrame et al. Understanding the pathways between drought and health across the WHO European Region - judovica.beltrame@bristol.ac.uk

Drought refugees

- In the case of drought migration, people may be forced to relocate to new areas due to a lack of water and food resources. This often occurs in arid or semi-arid regions, where drought conditions can lead to crop failure and loss of livelihood opportunities.
- People forced to relocate may experience substantial economic and social disruption. Drought migration significantly elevates the exposure to environmental hazards, overcrowding and increased risk of infectious diseases.
- Forced migration can lead to mental health issues due to the disruption to family and community networks, as well as the loss of familiarity with their home environment. As a part of social support, it is crucial to ensure that drought migrants have access to mental health services and other forms of social support.

Climate refugees

- In addition to drought migration, several other climate change-related events may force people to leave their habitats. According to statistics published by the Internal Displacement Monitoring Centre, every year since 2008, an average of 26.4 million persons around the world have been forcibly displaced by floods, windstorms, earthquakes.
- Today, the majority of displaced people find a new place to live domestically, but the risk of global displacement is increasing.
- International climate migration can generate severe public health risks.

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Emerging health risks of international climate migration

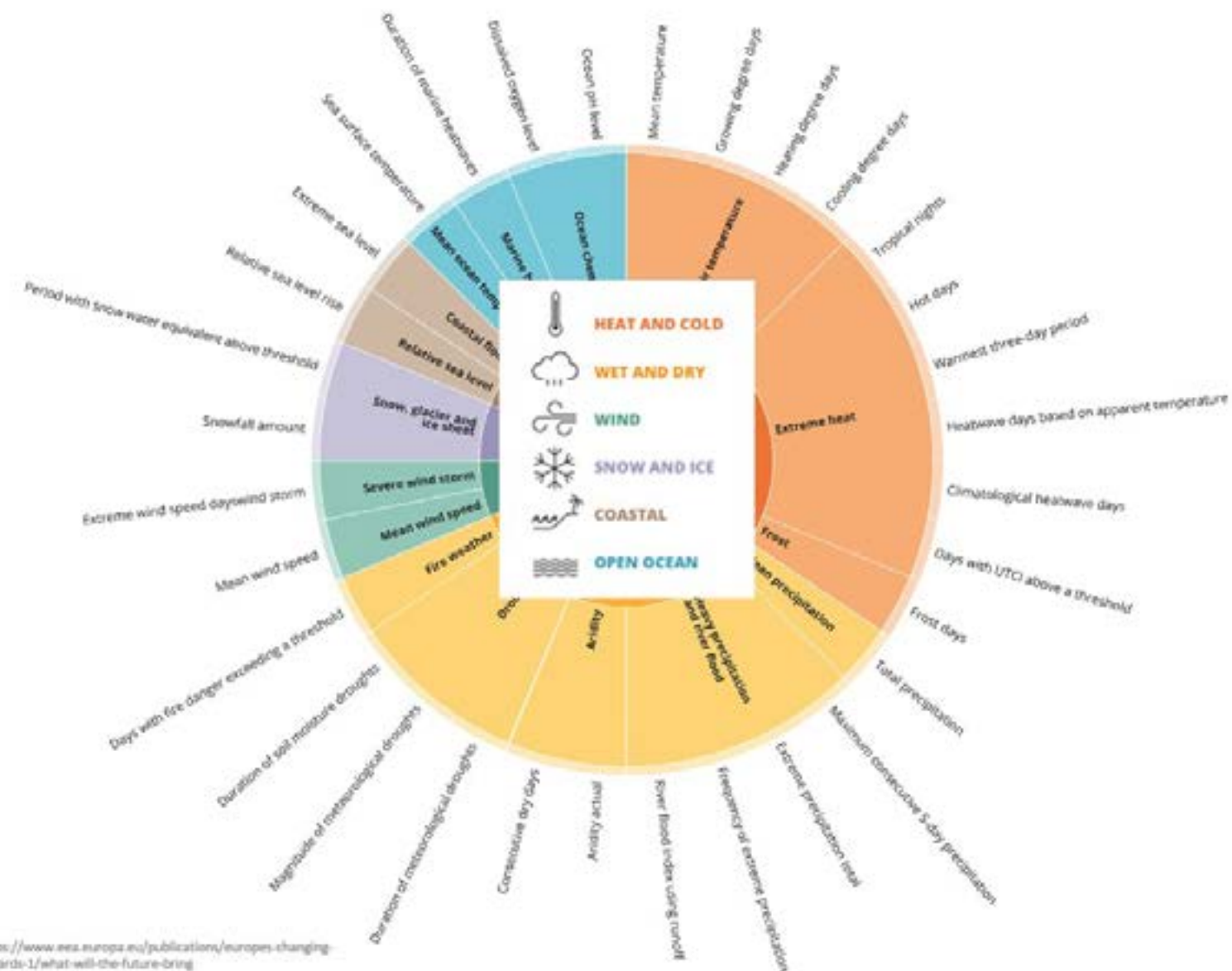
The communities of the target countries may be unprepared to meet the needs of the newly arrived population, leading to overcrowding, resource shortages, and social tensions:

- in climate migrants, the prevalence of certain diseases (tuberculosis, AIDS, others) may be multiplied higher in the country of origin than in the host country
- certain diseases are not typical for the target countries, so there may be difficulties in diagnosing and treating such unknown diseases (e.g. Dengue-fever, malaria, others)
- the same disease may show different signs and symptoms, and this may cause

difficulties in diagnosing (e.g. Varicella in black people)

- Climate migrants may arrive with poor health status due to the long and dangerous journey (e.g. trafficking); they are exhausted, maybe traumatized, or injured. Therefore, the target country is responsible for providing them with the necessary resources and assistance to ensure they receive the health and other care they need.

Extreme weather events



Source: <https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring>

Representative Concentration Pathway

- The Representative Concentration Pathway (RCP) describe four different 21st century pathways of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use.
- The pathways describe different climate futures, all of which are considered possible depending on the volume of GHG emitted in the years to come. Each RCP represents the following scenarios:
 - RCP 2.6 - a stringent GHG mitigation scenario
 - RCP 4.5 and RCP 6.0 - intermediate GHG emission scenarios
 - RCP 8.5 - the highest GHG emissions scenario

Heat and cold

- Mean air temperature will rise steadily across Europe.
- Hot extremes are expected to increase even faster than mean temperatures.
- By the end of the century, Europe as a whole and its three sub-regions are projected to experience further warming between a maximum of 1.5 °C (low-emissions scenario - RCP 2.6) and 4.5 °C (high-emissions scenario – RCP 8.5).

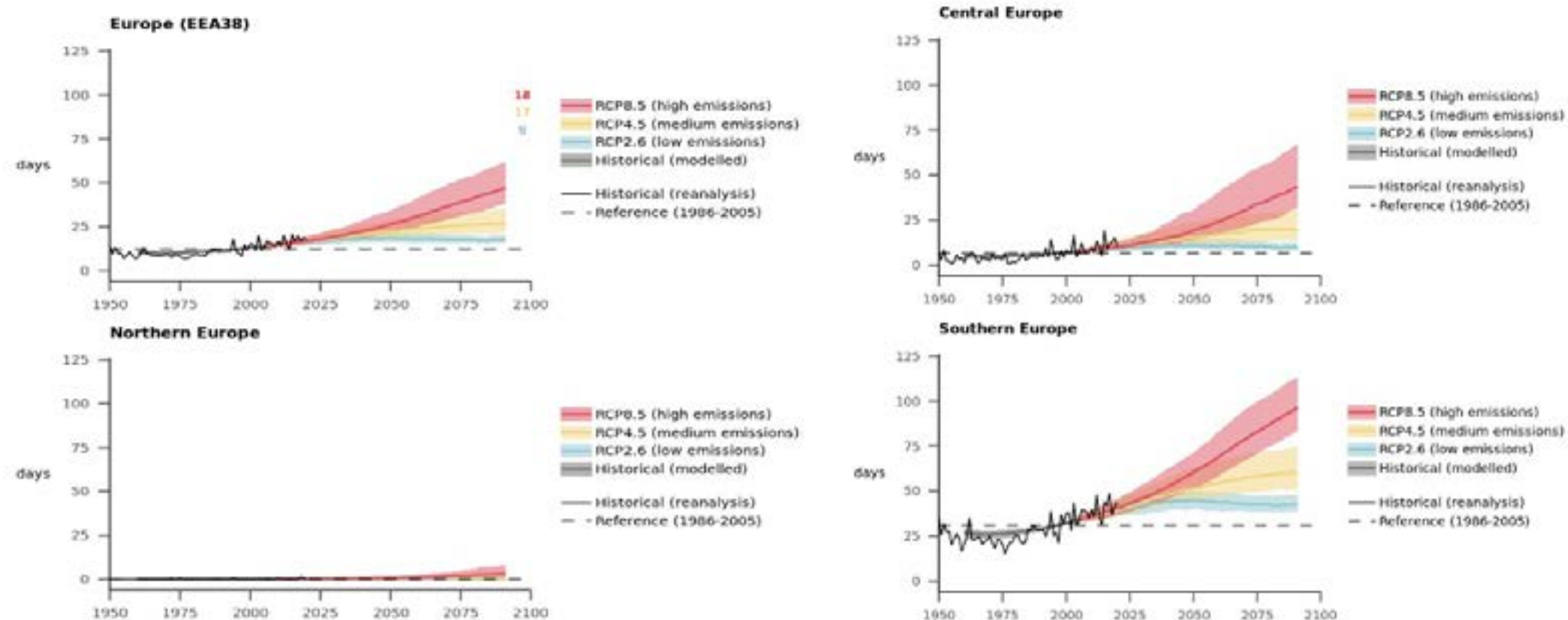
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- Mean air temperature will rise steadily across Europe. As a result, growing degree days and cooling degree days will increase, whereas heating degree days and days with frost will decrease.
- Hot extremes are expected to increase even faster than mean temperatures. Humid heatwaves, which pose a great risk to human health, are projected to increase rapidly across Europe.
- Changes in seasonal mean temperature are directly relevant for many sectoral applications, such as agriculture, forest and ecosystem management, and energy consumption.
- In addition, an increase in mean temperature together with increases in CO₂ concentrations and relative humidity can trigger climate change-induced corrosion of buildings and infrastructure.
- Extreme heat also affects transport and energy infrastructure, agriculture and biodiversity, and it increases the likelihood of wildfires.
- Urban areas are especially vulnerable to increasing heat stress because of the 'urban heat island' effect.

Annual hot days for the European land area and sub-regions



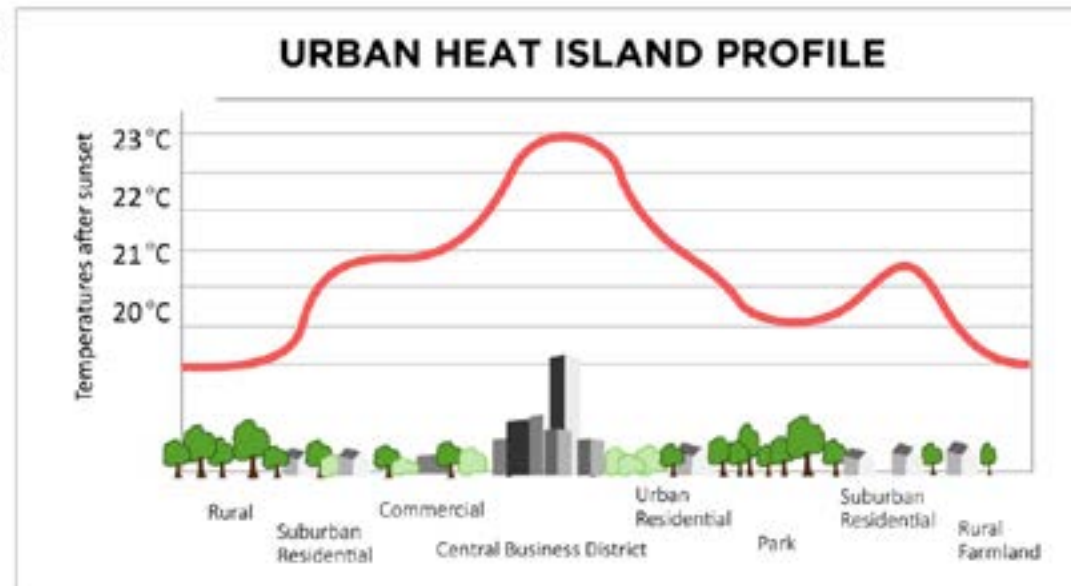
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Urban Heat Island



An urban heat island is a metropolitan area which is significantly warmer than its surrounding rural areas. The temperature difference is usually larger at night than during the day, and is most obvious when winds are weak.

→ The most obvious way to fight the urban heat island effect is to reintroduce vegetation. Cities can expand parkland, plant street trees, and install “green roofs” designed to harbour plant life: the presence of vegetation can lower nearby air temperatures by as much as around 1.5 °C

The man-made surfaces in urban environments tend to absorb and re-emit more heat from sunlight, which makes their surroundings warmer. Another source of heat is human activities like power generation and the use of cars and air conditioners. These conditions contribute to resulting in urban heat islands.

→ Urban heat islands can pose significant health risks. By heightening air temperatures and intensifying heatwaves, they can cause heat stroke and heat exhaustion as well as other illnesses, like heart attacks. These health impacts are often felt inequitably, with low-income and minority communities tending to live in areas more susceptible to heat islands.

→ Heat islands can also harm the environment. To cope with higher temperatures, cars and buildings consume more energy, which worsens air pollution and contributes to climate change.

Frost days

- The number of frost days in Europe has decreased since the 1980s, but with considerable year-to-year variability.
- The fastest absolute decline has been observed in northern Europe. This trend is projected to continue throughout the 21st century, and the number of frost days is expected to decline by about half during the 21st century under the high-emissions scenario (representative concentration pathway (RCP 8.5)).

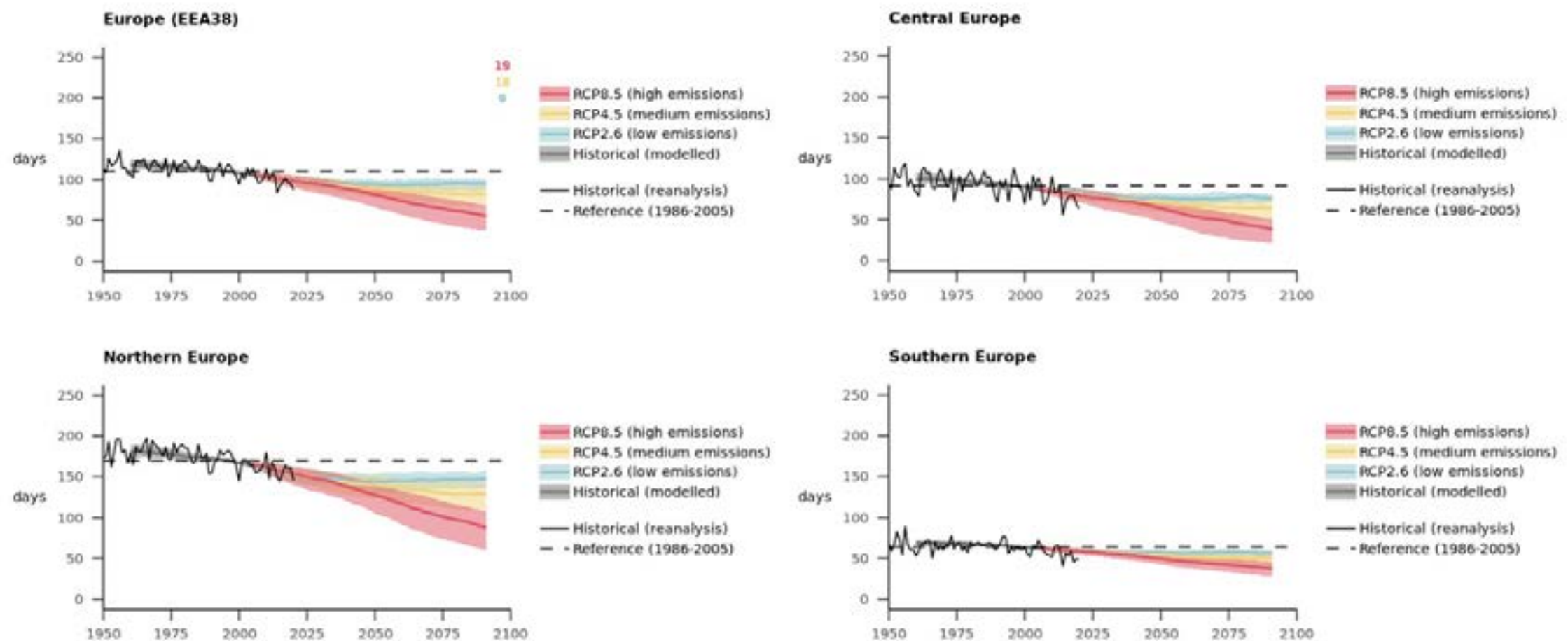
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- In Europe, the fruit and vegetable sectors are particularly affected by frost. Despite an overall decrease in frost days, an earlier start to the growing season could increase the risk of frost damage during the growing season.
- Frost timing can affect seasonal farming and cropping cycles in surprising ways (e.g. late spring frost before harvesting can be devastating for fruit trees, but some crops need frost during winter to stimulate flowering).
- Frost can affect the availability of fresh produce, especially fruits and vegetables that are susceptible to damage from freezing temperatures. This can lead to a reduction in the diversity and nutritional quality of diets, which can have negative health impacts.
- Reduced crop yields and increased demand for food due to crop frost damage can result in higher food prices, which can affect the ability of vulnerable populations to access nutritious food.

Annual frost days for the European land area and sub-regions



Source: <https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring>

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Wet and dry

- In northern Europe, annual precipitation and heavy rainfall are likely to increase, with droughts becoming less frequent. Mixed changes are expected for summer rainfall, flooding events, aridity and fire hazards.
- Central Europe is likely to experience lower summer rainfall, but also harsher weather extremes (heavy precipitation, river floods, droughts and fire hazards), with mixed changes in annual precipitation and aridity.
- In southern Europe, annual precipitation and summer rainfall are projected to decrease, whereas aridity, droughts and fire hazards are all likely to increase. Mixed changes are projected for heavy precipitation and river floods.

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Due to climate change impacts, projected changes in annual precipitation are expected to differ considerably across European regions and seasons.

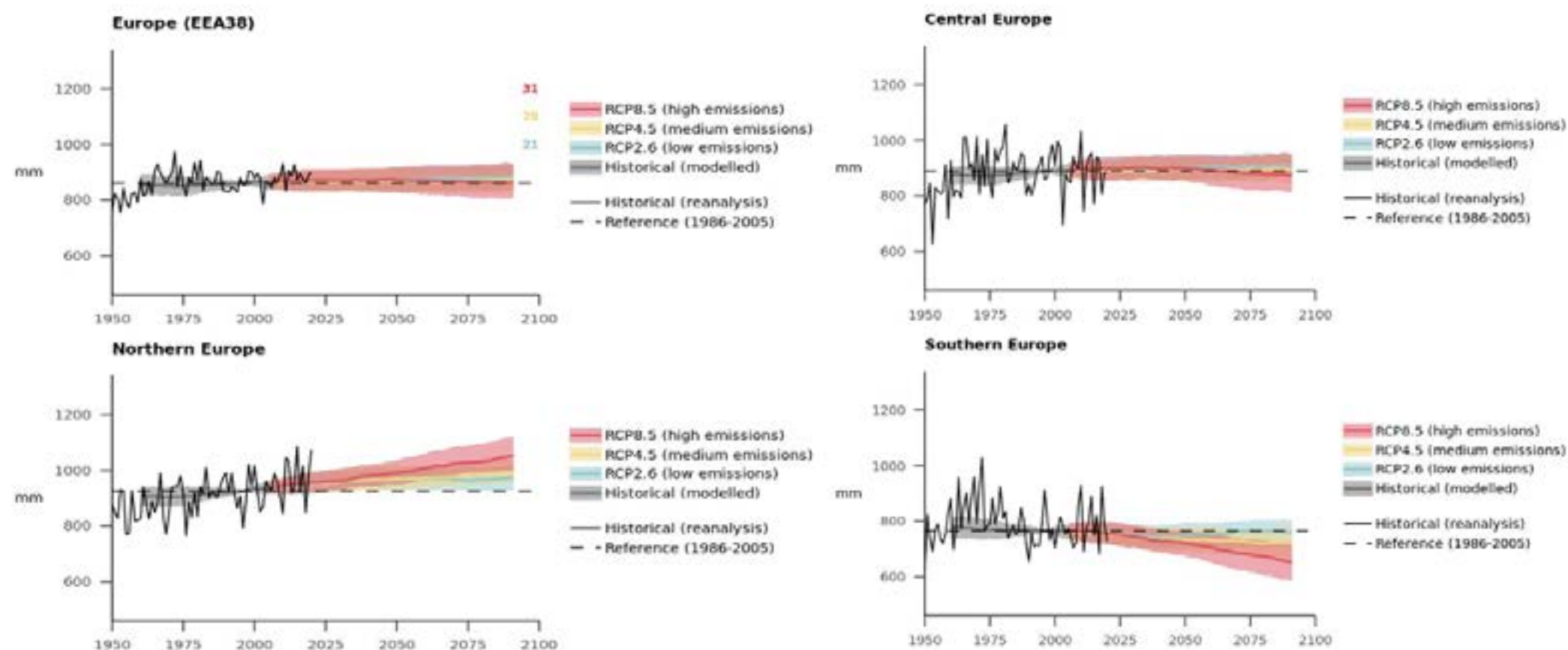
→ Annual precipitation of wet at the pan-European level shows substantial interannual variability, but a significant trend cannot be detected, neither in recent decades nor in projections.

→ Projections for precipitation during the summer, which is particularly important for natural ecosystems and agriculture, suggest that precipitation will decrease in central Europe, as well as in southern Europe, whereas no change is projected for northern Europe.

→ Winter precipitation is expected to increase in northern and central Europe, especially under the high-emissions scenario (representative concentration pathway (RCP 8.5).

→ However, the more frequent occurrence of extreme wet-related events, such as flash floods, are expected.

Annual precipitation for the European land area and sub-regions



Source: <https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring>

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Flash floods

- Flash flooding results from relatively short, intense bursts of rainfall, often from severe thunderstorms.
- It can occur in almost all parts of the world.
- Urban development in our towns and cities introduces hard surfaces such as roofs, roads, driveways and paths which stop rain soaking into the ground. This means more water runs off than would naturally occur.



fredericwiel.com, Flood in Liège, Belgium, 2011

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- In urban areas, the floodwater picks up potentially harmful substances from roads, factories, gutters and drains, including oil, household chemicals, and transfers them to streets and urban watercourses. This water poses risks to human health as it may contain toxins and pathogens such as E. coli and the virus that causes hepatitis A.
- There is also an increased risk of wound infections, dermatitis, conjunctivitis, and ear, nose and throat infections from polluted waters.

- In the case of flash flooding, people are often swept away after entering floodwaters on foot or in vehicles.
- Flash floods can occur in rural areas where the nature of terrain and steepness of the streams can lead to very rapid development of flooding.
- These floods can also result in significant property damage and major social disruption.
- During flash floods the risk of traffic accidents in both urban and rural environments is elevated.

- There can be significant risks from slip and trip hazards beneath the water. The flood waters may contain sharp objects, such as glass or metal fragments, that can cause injury and lead to infection.
- Water can also hide trip or slip hazards, such as rocks, steps, kerbs, tree roots, grass, mud or other debris. If water is fast moving, these hazards can lead to serious puncture wounds, bone breaks, or worse.

Urban flooding – health risks

Several infectious diseases, including water-borne, faecal-oral-borne and gastrointestinal diseases, can spread through contact with surfaces contaminated by flood waters.

The likelihood of illness increases when floodwater contains faecal material from overflowing sewerage systems, or agricultural or industrial wastes.



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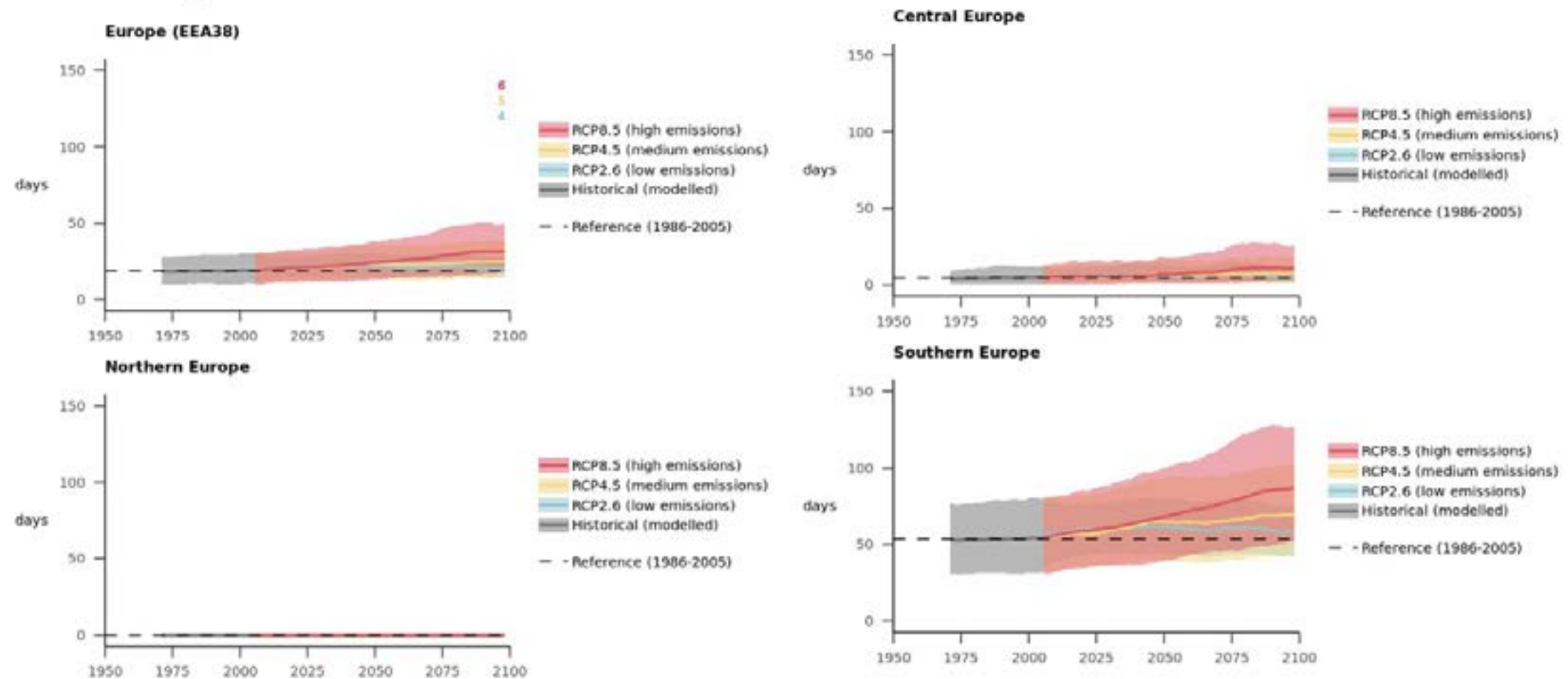
Aridity

- Dry spells are most persistent in southern Europe with a duration of almost 40 days, compared with about 20 days in northern and central Europe.
- The maximum annual number of consecutive dry days has been almost stable throughout Europe since the 1980s.
- Projections suggest that there will be no changes in dry spells in northern Europe, small increases of about 5 days in central Europe and larger increases of about 15 days in southern Europe throughout the 21st century under the high-emissions scenario (representative concentration pathway (RCP 8.5)).
- Even larger increases are possible in particular parts of southern Europe.

Days with high fire danger

- The annual number of days with high fire danger is projected to increase in Europe, whereby higher emissions scenarios are associated with larger increases.
- By far the highest absolute values and the largest increases are projected for southern Europe, but central Europe is also expected to experience increases.
- FWI values in northern Europe are projected to exceed the chosen threshold for high fire danger only rarely, even though large forest fires have recently occurred in this region.
- The uncertainty in future projections for this index is larger than for most other indices, which reflects the complex computation of this index involving the consideration of several essential climate variables.

Annual days with high fire danger (FWI value > 30) for the European land area and sub-regions



Source: <https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring>

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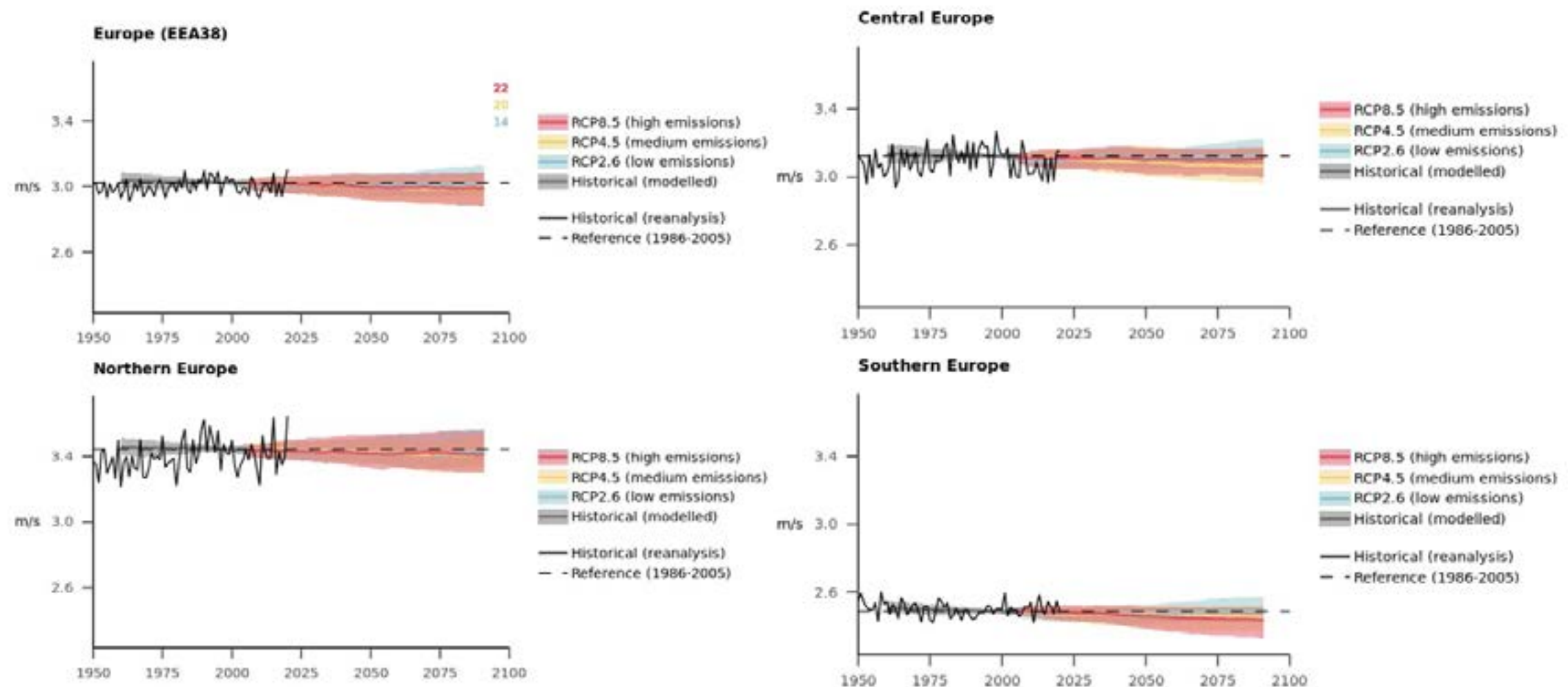
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Wind

- Mean wind speed is a particularly relevant indicator for the wind energy sector, because even small changes can have considerable effects on renewable energy production and the industries and populations that depend on it.
- Annual mean wind speed is generally higher in northern Europe and along coastlines than in southern Europe and inland.
- Climate models anticipate relatively minor changes in mean wind speed. Storm intensity is projected to increase across Europe, but changes in the frequency are projected to differ across regions. The Intergovernmental Panel on Climate Change's Sixth Assessment Report suggest that wind speeds are likely to decrease in southern and northern Europe.

Annual mean wind speed for the European land area and sub-regions



Source: <https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring>

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Snow and Ice

- Annual snowfall and snow cover extent have generally decreased across Europe, especially at lower elevations.
- Snowfall is projected to decrease substantially in future in central and southern Europe, where it could almost disappear in many low-elevation regions.
- Snow seasons have generally become shorter in northern, western and eastern Europe as a result of earlier snowmelt in spring.
- The length of the snow season is projected to decrease substantially in future, with reductions of more than 100 days by the end of the century in some regions.

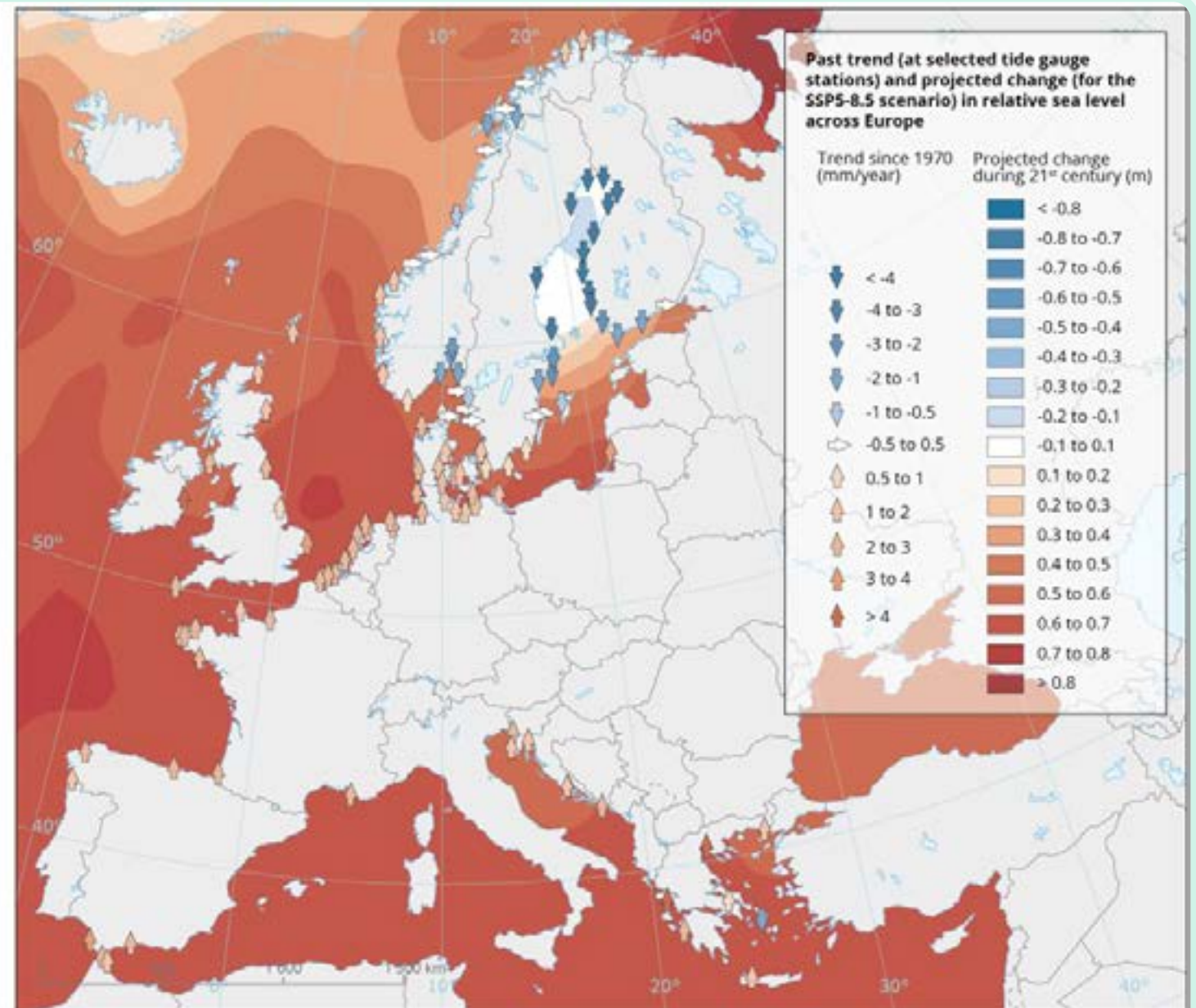
Costal

- More than one third of the European population lives in coastal regions. Low-lying countries, islands and communities know from experience that rising sea levels are a major climate hazard.
- Higher relative sea levels and corresponding storm surges threaten property, infrastructure and lives. They can lead to coastal erosion and make surface water and groundwater unusable through saltwater intrusion, with knock-on effects for agriculture and coastal and land ecosystems.
- Local sea level rise can be strongly affected by human activities, such as groundwater extraction or soil compaction from buildings.
- All this is crucial not only for coastal planning, ecosystem management and protection but also for putting in place measures to protect transport, energy and other infrastructure.

Past trends and projected changes in relative sea level across Europe

The arrows show the trends in relative sea level at selected European tide gauge stations since 1970. The background colours show the median of model projections of European sea level change for 2081-2100 for the high-emissions scenario (RCP 8.5).

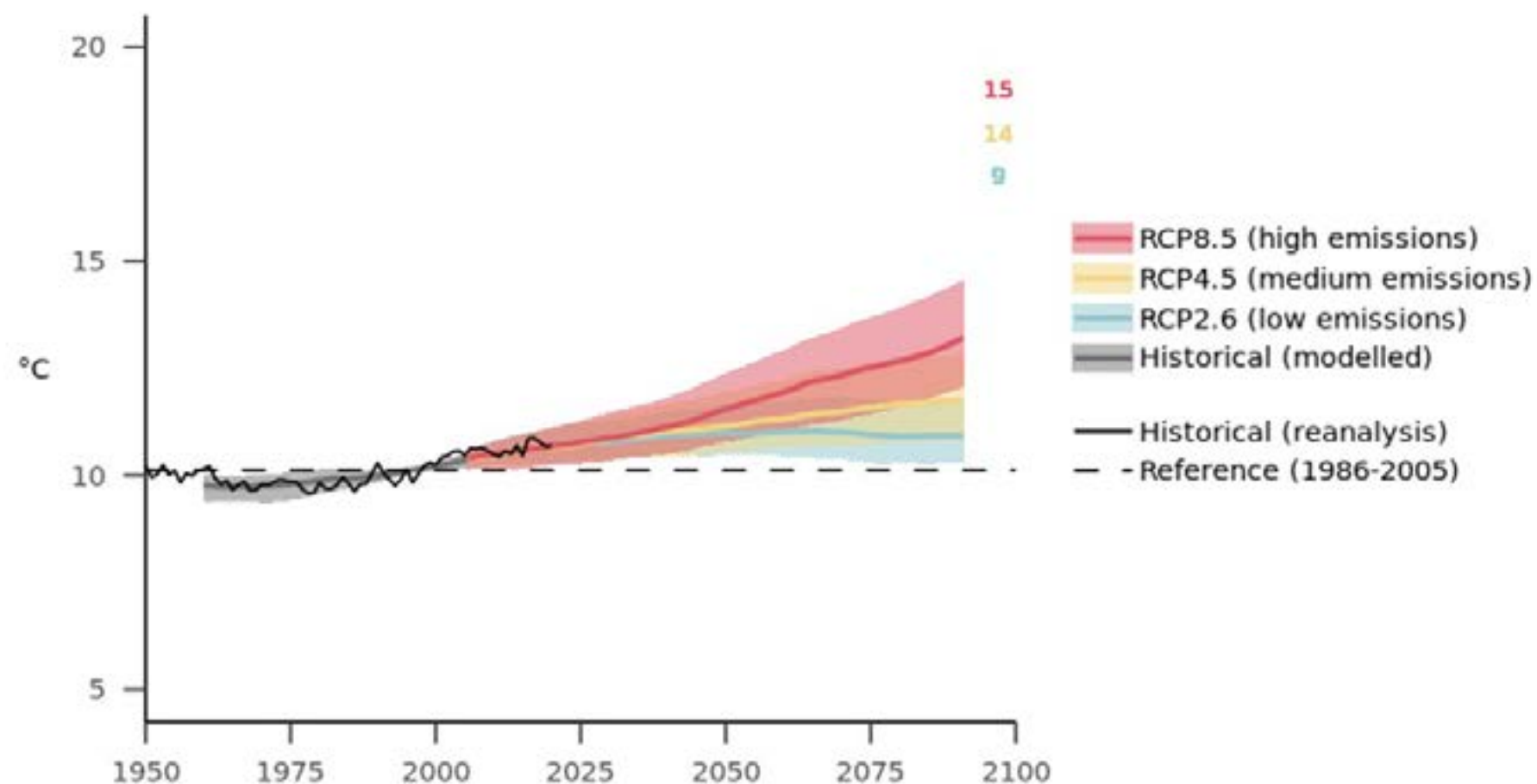
Source: <https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring>



Open ocean

- Sea surface temperature is projected to increase in all European regional seas, with associated increases in marine heatwaves.
- Changes in ocean temperature can have widespread effects on marine species and biodiversity, with direct and indirect impacts on both natural and human activities, from ecosystem services to the fishing industry. Higher ocean surface temperatures can increase water vapour in the atmosphere, which influences weather both at sea and over land.
- Ocean warming in coastal areas can trigger algal blooms and bacterial outbreaks, which can be dangerous to marine life, human health and industries relying on tourism, fisheries, etc.
- Europe's seas are also expected to become more acidic.

Sea Surface temperature



Source: <https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring>

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Take-home messages

- With the increase in frequency and intensity of extreme weather events, it is important to take them seriously.
- Ignoring these events can lead to devastating consequences for individuals, communities, and the environment.
- It is crucial to stay informed about weather patterns and heed warnings from local authorities.
- By taking proactive measures such as preparing emergency kits and evacuation plans, we can minimize the impact of extreme weather events and keep ourselves and other individuals safe.

Test your knowledge

List five health hazards of wildfire.

What does „Urban Heat Island” mean?

What are the typical hazards of a flash floods and urban flooding?

What is the association between the different levels of GHG emissions and environmental expositions for health?

Explain the correlation between varying levels of GHG emissions and their impact on environmental health.

Briefly summarise the health challenges related to drought and any potential strategies for adapting to these challenges.

What kind of environmental impacts are considered extreme weather events?

Recommended readings

Filho et al. (2022) Handling the health impacts of extreme climate events

<https://doi.org/10.1186/s12302-022-00621-3>

EEA (2022) Climate change as a threat to health and well-being in Europe: focus on heat and infectious diseases <https://www.eea.europa.eu/publications/climate-change-impacts-on-health>

WHO (2011) Public Health Advice on Preventing Health Effects of Heat

<https://www.who.int/publications/i/item/WHO-EURO-2011-2510-42266-58691>

Chen et al. (2021) Mortality risk attributable to wildfire-related PM2.5 pollution: a global time series study in 749 locations DOI:[https://doi.org/10.1016/S2542-5196\(21\)00200-X](https://doi.org/10.1016/S2542-5196(21)00200-X)

What will the future bring when it comes to climate hazards?

<https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring>

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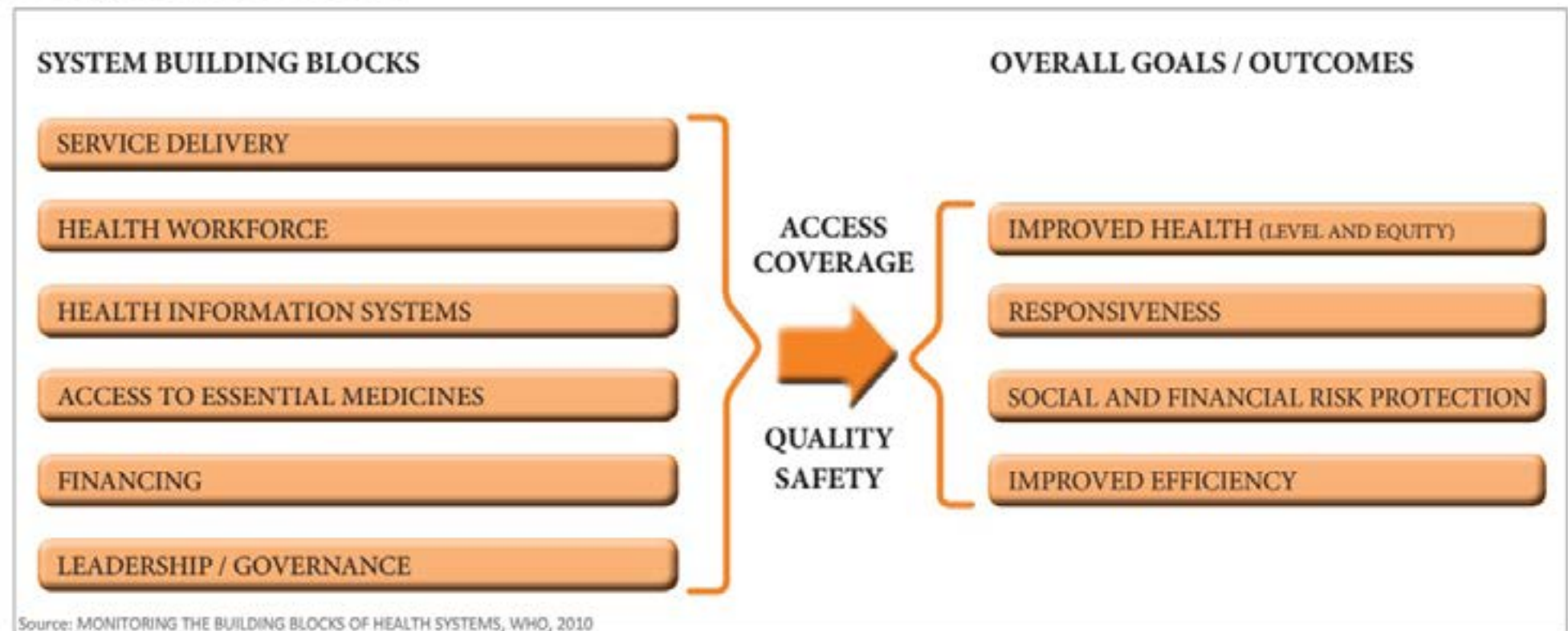
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Greening healthcare system, adaptation, inequalities

Healthcare System

The WHO defines the health sector as all organizations, institutions, and resources that are devoted to producing health actions.



A health action is defined as any effort, whether personal healthcare, public health service or intersectoral initiative, whose primary purpose is to improve health.

Rationale of greening healthcare system

Climate change confronts the healthcare sector with a dual challenge:

- Accumulating climate impacts are putting an increased burden on the service provision of already stressed healthcare systems in many regions of the world.
- At the same time, the Paris agreement requires rapid greenhouse gas (GHG) emission reductions in all sectors of the global economy to stay well below the 2 °C target.

In the healthcare sector, as in other service sectors in general, direct emissions are relatively low compared to other sectors.

The emissions along the supply chain, induced by purchases of goods and services by the healthcare sector, can account, however, for a significant share of the national CO₂ footprint.

Definitions of GHG sources and activities along the value chain by scopes for various sectors

Scope 1: Electricity indirect GHG emissions

Scope 2: Indirect GHG emissions

Scope 3: Indirect GHG emissions

Scope 3: Indirect GHG emissions

- These emissions are indirect: that occur in the value chain of an organization but are not directly owned or controlled by the organization.
- It encompass a wide range of activities and sources that occur upstream or downstream of the organization's operations, including activities such as purchased goods and services, transportation and distribution, waste disposal, employee commuting, business travel, and the use and disposal of products sold.

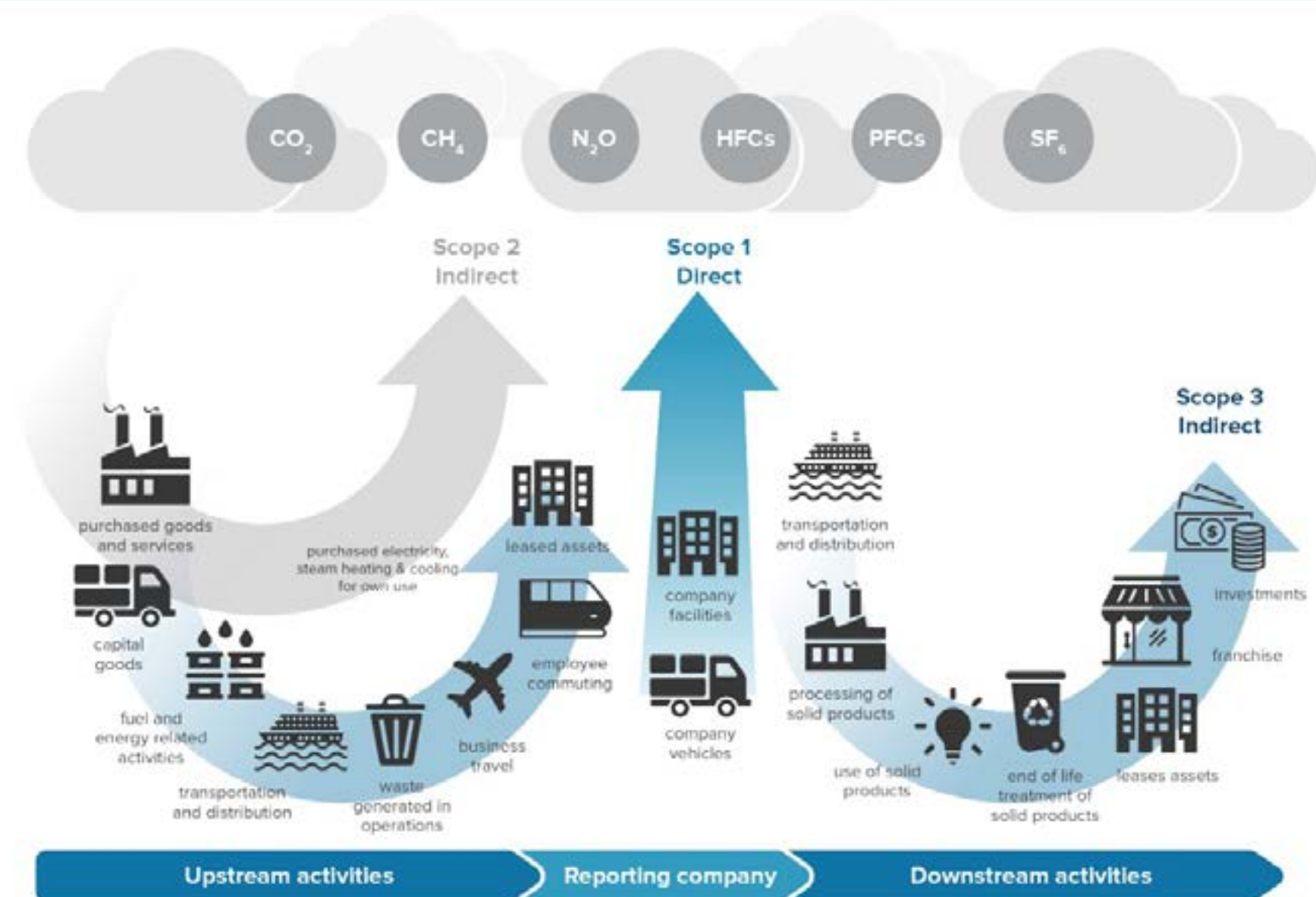
Scope 1 Electricity indirect GHG emissions

- Generation of electricity, heat, or steam (emissions result from combustion of fuels in stationary sources)
- Physical or chemical processing (emission result from manufacture or processing of chemicals and materials)
- Transportation of materials, products, waste, and employees (emissions result from the combustion of fuels in company owned/ controlled mobile combustion)
- Fugitive emissions (emissions result from intentional or unintentional releases, e.g., equipment leaks from joints, seals, packing, gaskets; coal mines' methane emissions)

Scope 2: Indirect GHG emissions

- These emissions are indirect: they are generated by a third party, such as a utility company, but they are considered direct emissions for the reporting organization because they result from its consumption of electricity or heat.
- It is necessary to know that Scope 2 emissions do not include the emissions associated with producing the purchased electricity, heat, or steam. These emissions are accounted for in Scope 1 (direct emissions) if the organization generates its energy or in Scope 3 (indirect emissions) if they are generated by an external supplier upstream of the organization's activities.

GHG sources and activities



Source: ISBN 978-1-56973-772-9

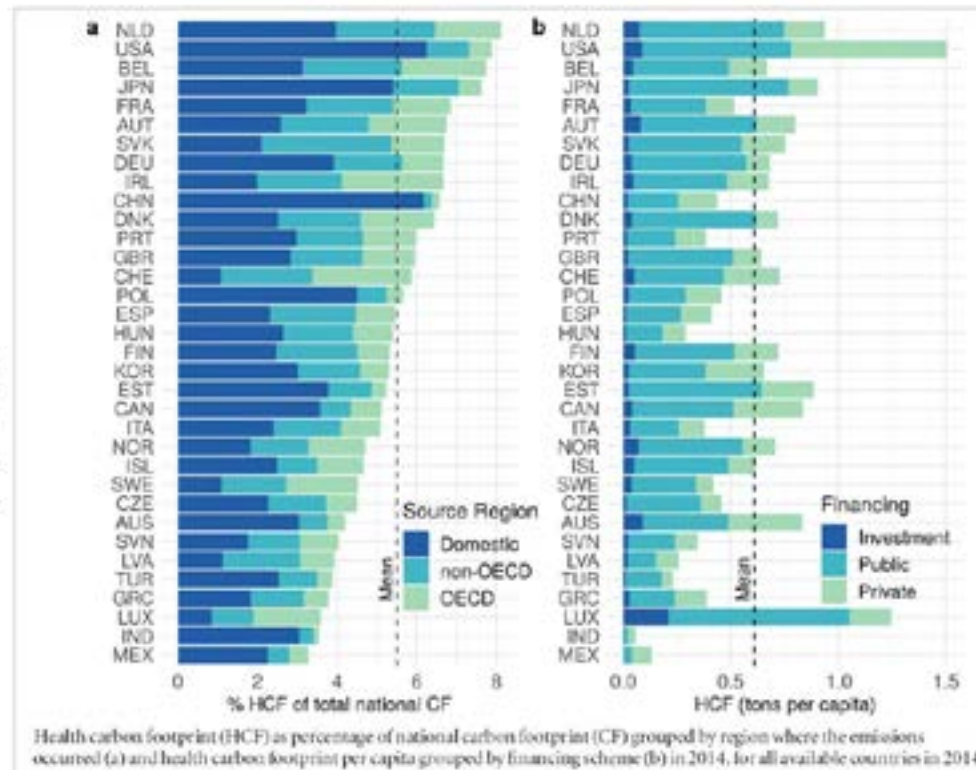
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Carbon Footprints of Healthcare Systems

Calculating a carbon footprint allows organizations to understand the environmental impact of their activities and identify areas for emission reductions.



The global healthcare sector had a carbon footprint of 2.0GtCO₂e in 2014, equivalent to 4.4% of global net emissions.

A carbon footprint is the total amount of greenhouse gases (GHG) that are generated by a specific activity (e.g. production, processing and retailing of consumer goods, and provision of services).

The carbon footprint takes into account not only the direct emissions (Scope 1) but also the indirect emissions (Scope 2 and Scope 3) associated with the entire lifecycle of products, services, and activities.

It serves as a baseline for making informed decisions to mitigate climate change.

If healthcare system were a country, it would be the fifth largest emitter on the planet.

Emissions emanating directly from healthcare facilities (Scope 1) make up 17% of the sector's worldwide footprint.

Indirect emissions from purchased electricity, steam, cooling and heating

(Scope 2) comprise another 12%.

The majority of Healthcare Systems' emissions (71%) come from what is known as Scope 3, and are primarily derived from the healthcare supply chain – the production, transport, use, and disposal of goods and services that the sector consumes.

Reducing Carbon Footprints of Healthcare Systems

The carbon footprint can be reduced by the use of appropriate low-carbon technology for care such as:

- low-carbon or net zero emissions building design and construction;
- investment in renewable energy and energy efficiency;
- climate-smart cooling technologies;
- sustainable waste, water, and transport management;
- minimizing the use of high global warming potential anaesthetic gases;
- decentralized models of care (e.g. telemedicine);
- building resilient and healthier communities.
- others.

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Decentralization – a step forward to sustainable healthcare

Decentralized model of healthcare system allows for greater flexibility in the delivery of care: instead of relying on a centralized system that may not be able to respond quickly to changing needs, healthcare providers can adapt to the unique challenges of their communities and patients.

Local healthcare providers can better understand the specific health risks associated with climate change in their area and tailor interventions and services accordingly. This enables targeted responses to address the unique challenges and vulnerabilities faced by different communities.

In this way, unnecessary or rare-used services and related infrastructures can be reduced, and the efficiency of healthcare benefits can be enhanced.

Health inequalities

Health Inequalities are the differences in health status between groups of people which are important, unnecessary, unfair, unjust, systematic, and avoidable by reasonable means.

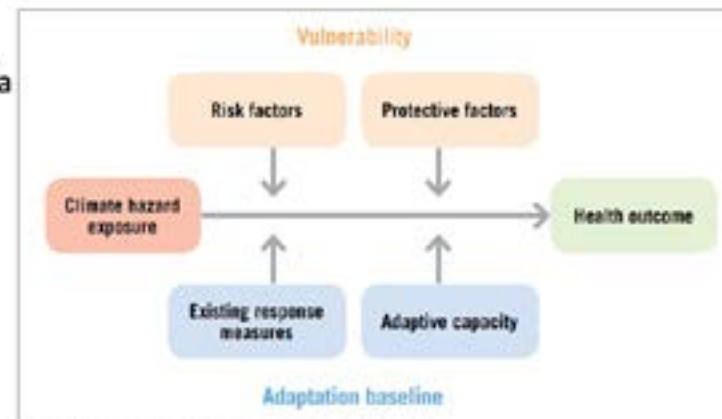
These differences are linked to social, economic, and environmental conditions in which people are born, grow, live, work and age, and they often connected to wider inequalities and forms of discrimination in society, such as racism and sexism as well as economic imbalances.

Climate change interacts with existing social determinants of health, such as poverty, discrimination, and unequal access to resources. These factors create a compounding effect, making vulnerable populations even more susceptible to the health impacts of climate change.

Vulnerability

Defining the vulnerability in the context of climate change's health impacts is to look at populations that are particularly susceptible to

- the effects of extreme weather events (such as the elderly or those with preexisting medical conditions);
- the impact of climate change on food and water security, which can disproportionately affect low-income communities and exacerbate health disparities;
- specific regions to vector-borne diseases like malaria and dengue fever can increase as temperatures rise and precipitation patterns shift;
- the other possible dimensions of climate change.



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Various information categories must be combined in a conceptual indicator framework to provide information on the causal pathway of risk and protective factors that lead from exposure to adverse health effects.

Baseline and target indicators can be inferred from these information categories. The results will be informative as to which subpopulations are vulnerable and where they are located, as well as to the range of adaptation options relevant to reducing the ultimate burden of disease.

Understanding these different dimensions of vulnerability is essential for developing effective strategies to mitigate the health impacts of climate change.

Example of health vulnerability in the context of climate change:

Elderly are at increased risk from hotter summers and heat waves

Older people are more sensitive to heat because of their weaker ability to thermo-regulate and because they have other medical conditions.

They are also more likely to have prescribed medication, some of which is associated with an increased risk for heat-related death.

The adaptive capacity of the elderly may be limited by isolation or lack of information, mobility or autonomy.

Lack of autonomy, and lack of care staff awareness and preparedness, may, for example, prevent or obstruct behavioural and other adaptations in residential or nursing homes.

The alignment of the above factors accentuates the vulnerability of older people.

Example of health vulnerability in the context of climate change:

Elderly are at increased risk from pollen exposure

Pollen is one key factor in asthma, which can trigger inflammation of airways, coughing and breathing difficulties among people whose immune systems have become hypersensitive to triggers like pollen.

Climate change can impact pollen production and distribution: warmer temperatures can prolong the pollen season and lead to the emergence of new sources of pollen as plant species shift due to warming.

Older people with asthma have a five times higher risk of asthma-related mortality compared to younger individuals. Older people with asthma also frequently experience other adverse outcomes and often have comorbidities such as cardiovascular disease.

Example of health vulnerability in the context of climate change:

Increased air pollution-related health risk in association with social deprivation

Climate change increases O₃ and PM concentrations in the air.

Social deprivation and age pre-dispose people for cardiovascular illnesses, which in turn compounds the effects of elevated O₃ and PM concentrations on their health.

Women in routine jobs experience five times higher cardiovascular disease mortality than women in managerial and professional jobs. These differences in cardiovascular mortality risk and sensitivity to O₃ and PM pollution emerge from differences in the levels of deprivation, lifestyles, health literacy, access to health services, and environmental exposure.

Social deprivation and ethnicity can also constrain adaptive capacity by limiting ability to relocate and to take other measures to avoid exposure or to reduce sensitivity.

Example of health vulnerability in the context of climate change:

Food borne diseases and constraints on food production

Inadequate sanitation and poor hygiene practices are key contributors to foodborne diseases. Vulnerable populations may lack proper sanitation infrastructure, including access to clean water, sanitation facilities, and hygiene education.

The increased flooding and water scarcity, can exacerbate these challenges and further compromise sanitation and hygiene, increasing the risk of foodborne illnesses.

Climate change-induced constraints on food production can lead to food insecurity and malnutrition, particularly among vulnerable populations.

Malnutrition weakens the immune system, making individuals more susceptible to infections and increasing the severity of foodborne diseases.

Example of health vulnerability in the context of climate change:

Pressures on the healthcare system

Inpatients and people with urgent medical needs will be most exposed to the impacts of extreme weather on healthcare systems.

Rural dwellers are more exposed to disturbance from cold spells and flooding, while urban residents are more exposed to disturbance due to heat waves.

Many of the exposed will be older people who are sensitive to care disruptions and reduced access to care because of pre-existing medical conditions such as cardio-vascular disease and respiratory diseases, which are aggravated by climate change impacts.

Adaptive capacity is restricted among those who are in residential care and have limited control over their circumstances, and among those who are isolated or have reduced mobility.

Climate justice

Addressing health inequalities related to climate change requires a focus on climate justice. This involves recognizing the disproportionate impacts of climate change on vulnerable communities and implementing equitable policies and strategies to mitigate and adapt to climate change.

Climate justice advocates for a transition to a low-carbon, sustainable future that prioritizes social and economic justice. It emphasizes the need for an equitable distribution of the costs and benefits of transitioning to renewable energy, green jobs, and sustainable development.

It aims to ensure that no one is left behind during this transition and that workers and communities dependent on high-carbon industries are supported in the shift to cleaner alternatives.

Adaptation

Adaptation refers to adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects. It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change.



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Adaptation to climate change's health impacts involves taking proactive measures to minimize the negative health consequences associated with changing climatic conditions.

Adaptation actions can take on many forms, depending on the unique context of a community, business, organization, country or region. There is no "one-size-fits-all-solution": it can range from building flood defences, setting up early warning systems for cyclones, switching to drought-resistant crops, to redesigning communication systems, business operations and government policies.

Countries and communities need to develop adaptation solutions and implement actions to respond to current and future climate change impacts.

Adaptation need to be based on and guided by the best available science and traditional knowledge, knowledge of indigenous peoples and local knowledge systems, with a view to integrating adaptation into socioeconomic and environmental policies and actions.

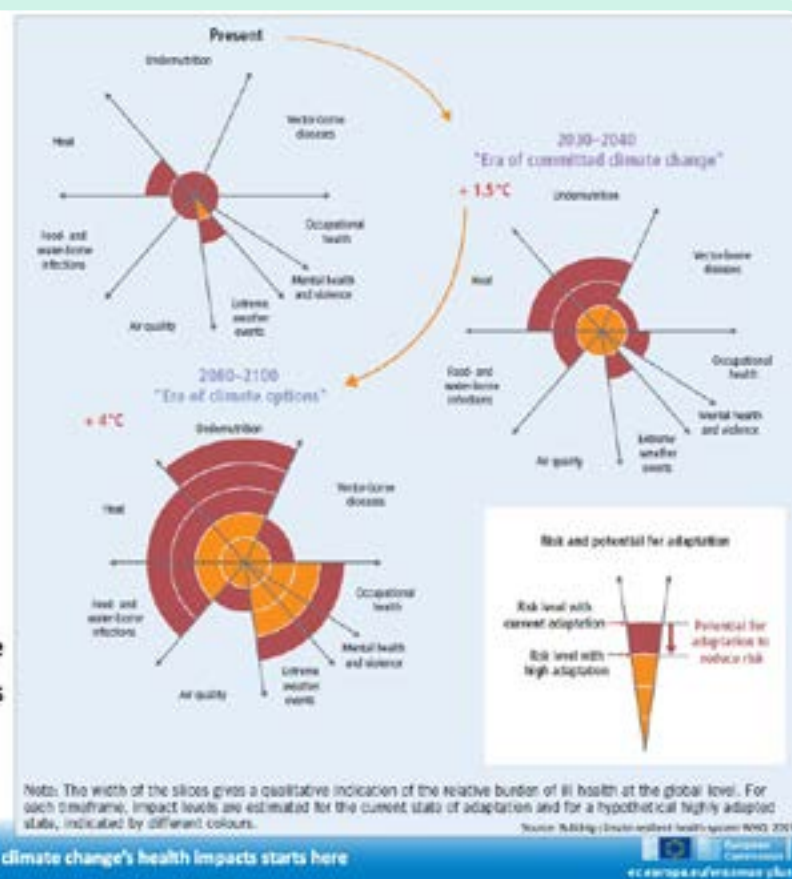
The strategy of private preparedness and responsibility would emphasise public information campaigns and public health education to make people aware of the

- health risks associated with climate change,
- factors contributing to people's exposure and sensitivity,
- alternatives for avoiding and mitigating adverse health outcomes, so that they can protect themselves.

Solutions such as advance warning systems would also support such strategies, signalling that people should deploy adaptation measures.

Potential for risk reduction through adaptation

The different colours indicate the extent to which disease burdens could be avoided by effective adaptation measures in each period.



The diagram provides a qualitative assessment of the future burden (for the period 2030-2040) of ill-health due to current climate change, in which the world will inevitably experience approximately 1.5 °C of warming due to past and present greenhouse gas emissions.

The diagram also presents the period

2080-2100, for which the global mean temperature is expected to increase by approximately 4 °C above preindustrial levels, unless vigorous mitigation efforts are undertaken soon.

Key strategies for adapting to the health impacts of climate change

Heatwave preparedness: developing heatwave early warning systems, implementing heat action plans, and providing public awareness campaigns to educate individuals about heat-related risks and protective measures.

This includes

- providing access to public cool spaces (malls, shopping centres, libraries, others);
- distributing heat-health warnings;
- educating people (about the specific health risks associated with climate change, how to assess their vulnerabilities, prepare for extreme weather events, and develop adaptive strategies to protect their health and well-being, others)
- ensuring vulnerable populations have access to appropriate cooling measures.

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Enhancing resilience to extreme weather events: implementing measures to reduce the health risks associated with extreme weather events such as hurricanes, floods, and wildfires. This involves

- improving emergency response systems;
- strengthening infrastructure (e.g. transportation, water and sanitation, energy, coastal, healthcare, communication infrastructures) to withstand climate-related hazards;
- promoting community resilience through early warning systems, evacuation plans, and disaster preparedness.

Improving disease surveillance and early warning systems: these measures may support to detect and respond to climate-sensitive diseases and includes monitoring vector-borne diseases, waterborne diseases, and other climate-related health risks to enable timely intervention and control measures.

Foster collaboration and data sharing among different stakeholders, including health departments, meteorological agencies, research institutions, and international organizations are also needed. This facilitates the integration of climate and health data, improves forecasting capabilities, and enhances preparedness and response to climate-related health risks.

Strengthening healthcare systems: ensure the resilience of healthcare facilities to continue providing essential services during climate-related emergencies. This includes designing hospitals and clinics to withstand extreme weather events, ensuring backup power systems, and developing emergency response plans that account for climate-related risks.

Training healthcare professionals in climate communication to effectively relay climate-related health information to patients, communities, and other healthcare professionals. Teach professionals how to translate complex climate science into accessible language, promote behavior change, and address misconceptions or denial regarding climate change.

Developing climate-resilient infrastructure

- Bolster energy infrastructure to withstand climate-related hazards and support a transition to renewable energy sources. This can involve reinforcing power grids, diversifying energy sources, promoting distributed energy systems, and improving the resilience of energy generation and distribution networks.



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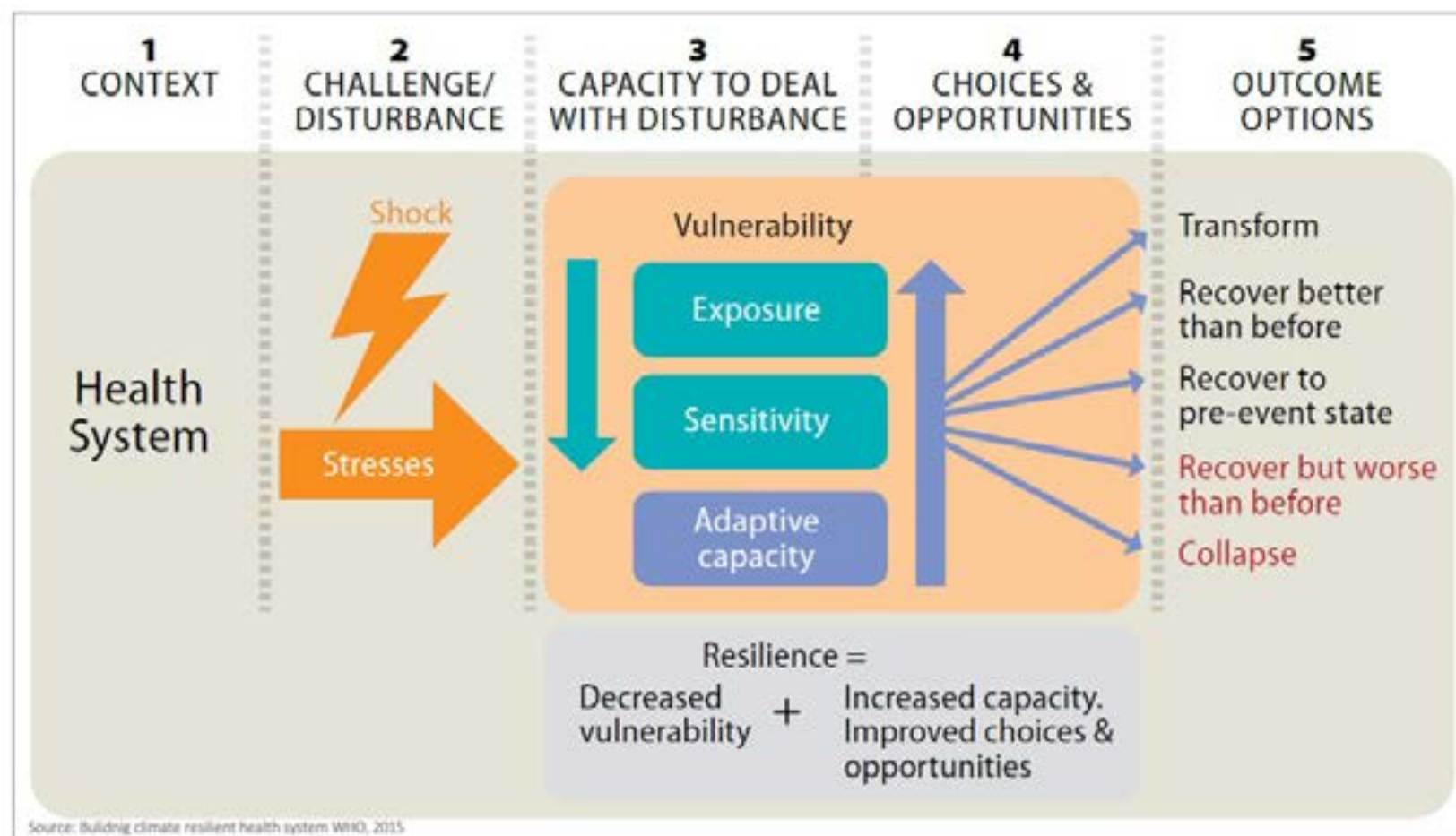
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- Enhance water and sanitation infrastructure to cope with changing precipitation patterns and increased flooding. This includes improving stormwater management systems, upgrading wastewater treatment plants to handle higher volumes, and ensuring the reliability and safety of drinking water sources.
- Protect coastal areas by fortifying infrastructure against sea-level rise, storm surges, and erosion. This may involve constructing seawalls, restoring natural coastal defenses like mangroves and dunes, and implementing coastal zoning regulations that restrict development in vulnerable areas.
- Strengthen communication and information systems to enable effective response and coordination during climate-related emergencies. This involves expanding and securing telecommunications networks, and ensuring the availability of reliable and resilient data centers.
- Enhancing food security and nutrition: implementing strategies to ensure food security and nutrition in the face of climate change by supporting small-scale farmers, diversifying food sources, and improving access to nutritious food for vulnerable populations.
- Promoting climate-smart agricultural practices, investing in irrigation systems, developing drought-resistant crop varieties, and diversification of food systems to reduce dependence on a few staple crops and enhance nutritional diversity are also critical.
- Promote sustainable land management practices to mitigate soil degradation, erosion, and loss of fertility. This includes agroforestry, conservation agriculture, terracing, and reforestation efforts is required as well.
- Community engagement and capacity-building: conduct outreach and educational campaigns to raise awareness about climate change and its health impacts. Provide information on the specific risks faced by the community and the importance of taking action. Use various mediums such as workshops, community meetings, social media, and local media to disseminate information.
- Provideing resources, technical support, and funding to empower communities to develop and implement their own adaptation plans. Encouraging the utilization of local knowledge and traditional practices that have proven effective in adapting to climate variability.
- Promoting citizen science initiatives that involve community members in data collection and monitoring of climate and health indicators. This empowers communities to generate their own localized data, contributing to early warning systems, surveillance efforts, and evidence-based decision-making.

Resilience and climate change's health impact

Resilience is intrinsically linked to adaptation.

A climate-resilient healthcare system is one that is capable to anticipate, respond to, cope with, recover from and adapt to climate-related shocks and stress, so as to bring sustained improvements in population health, despite an unstable climate.



Components for building climate resilient health systems

Building capacities and implementing strategies to minimize negative impacts and promote well-being in the face of climate-related challenges is a crucial aspect of resilience.

Whether it be in personal or professional situations, the resilience means being flexible and adaptable, and willing to make changes when necessary.



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Key aspects of resilience in terms of climate change's health impacts

Adaptive capacity: includes taking proactive steps such as implementing early warning systems, preparedness plans, and infrastructure improvements to minimize vulnerability to climate-related health impacts. In addition, adaptive capacity also involves fostering flexibility and learning from past experiences to continually enhance responses to climate change.

Health system readiness: healthcare systems need to be prepared to handle climate-related health risks. Hence, the healthcare infrastructure must be strengthened:

- ensuring access to essential health and social services;
- training healthcare professionals on climate-related health issues;
- developing response plans for emergencies and outbreaks exacerbated by climate change.

Health information systems that include

- information on vulnerability to climate risks
- disease surveillance;
- research programmes to monitor health-related progress against persistent and emerging threats;
- existing and expected future capacity of the system to respond, and identification of adaptations;
- integration of climate information into disease surveillance providing an opportunity to develop early warning systems and more accurate target interventions.

Community engagement and empowerment: resilience is enhanced when communities are engaged and empowered to actively participate in decision-making processes and take actions to protect their health in the face of climate change.

Components for building climate resilient health systems

Building capacities and implementing strategies to minimize negative impacts and promote well-being in the face of climate-related challenges is a crucial aspect of resilience.

Whether it be in personal or professional situations, the resilience means being flexible and adaptable, and willing to make changes when necessary.



Source: Building climate resilient health systems WHO, 2023

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Achieving these goals, the following activities would be more than beneficial both for individuals and neighbourhoods:

- raising awareness about climate-related health risks;
- providing education and resources for individuals and communities to develop health literacy and make informed decisions;
- supporting community-led initiatives to adapt and build resilience.

Multi-sectoral collaboration: is essential for building resilience to climate change and its impacts. Bringing together various sectors, and expertise to address complex challenges and develop comprehensive solutions is critical.

Engaging stakeholders from different sectors, including businesses, civil society organizations, community groups, academia, and vulnerable populations, is crucial.

Addressing climate change health impacts involves integrating climate considerations into sectoral policies and practices across these sectors to ensure a coordinated and comprehensive response.

Addressing underlying vulnerabilities: to develop resilient and inclusive communities it is crucial addressing the underlying social, economic, and environmental determinants of health.

Related initiatives should address issues such as

- poverty;
- social exclusion and inequality;
- inadequate housing;
- limited access to healthcare.

These determinants can exacerbate the health impacts of climate change, particularly for vulnerable populations.

Long-term thinking and planning: resilience involves adopting a long-term perspective in assessing and addressing climate change health impacts.

On an operational level, long-term thinking and planning include:

- considering future climate scenarios;
- conducting risk assessments;
- incorporating climate projections into health planning and policy development;
- integrating climate change considerations into development plans to prioritise health and well-being.

Take-home messages

If healthcare system were a country, it would be the fifth largest emitter on the planet. The majority of Healthcare Systems' emissions (71%) come from the production, transport, use, and disposal of goods and services that the sector consumes.

Climate change interacts with existing social determinants of health, such as poverty, discrimination, and unequal access to resources. These factors making vulnerable populations even more susceptible to the health impacts of climate change.

Adaptive capacity includes taking proactive steps such as implementing early warning systems, preparedness plans, and infrastructure improvements to minimize vulnerability to climate-related health impacts.

To develop resilient and inclusive communities it is crucial addressing the underlying social, economic, and environmental determinants of health.

Test your knowledge

What does „climate change confronts the healthcare sector with a dual challenge” mean?

What are the Scope 1, 2, and 3 scopes in the context of GHG sources?

What does „health inequality” mean?

What is the main source of the Healthcare Sector’s GHG emissions?

What is the difference between mitigation and adaptation?

How can be „climate justice” defined?

How can disease surveillance and early warning systems contribute to adapting to climate change's health impacts?

What are the characteristics of a climate-resilient healthcare system?

Recommended readings

WHO (2020) guidance for climate resilient and environmentally sustainable health care facilities <https://www.who.int/publications/i/item/9789240012226>

Paavola (2017) Health impacts of climate change and health and social inequalities in the UK <https://doi.org/10.1186/s12940-017-0328-z>

WHO (2015) Operational framework for building climate resilient health systems <https://www.who.int/publications/i/item/9789241565073>

WHO (2014) Guidance to protect health from climate change through health adaptation planning <https://www.who.int/publications/i/item/9789241508001>

United Nations Climate Change – Adaptation and resilience <https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/introduction>

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