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Health effects of climate change

An update of the current risks of climate change for health

RIVM letter report 2024-0102
C.D. Betgen et al.

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Colophon

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Synopsis

Health effects of climate change

An update of the current risks of climate change for health

The climate is changing worldwide, and therefore also in the Netherlands. The average temperature has increased over the past century. There is more precipitation, there are more periods of dry weather and days with temperatures above 25 degrees Celsius are now more frequent in the Netherlands. RIVM has studied the effects of climate change on our health over the past 30 years (1991–2020). Major health impacts are already visible, and they are expected to increase.

This study focuses on the health effects of heat, UV radiation, air quality, (pollen) allergies and infectious diseases due to climate change. Mental health effects are also included. The study illustrates that climate change worsens health and explains how this happens. However, the extent to which this happens is often more difficult to determine because other factors also affect health. More knowledge is needed to get a better picture of the impact of climate change and to be able to give sound advice on policies to protect health.

The strongest evidence for the effects of climate change on health concerns the number of additional deaths due to higher average annual temperatures: an average of 250 deaths per year. Climate change leads to warmer days (above 20 degrees Celsius). There are also more heatwaves, which last longer and are hotter. As a result, more people die than usual.

Hot and dry weather often occurs at the same time as a lot of pollen in the air and high concentrations of ozone (summer smog). This can make people experience shortness of breath, especially if they already have a respiratory disease. The growing season lasts longer these days, and there is more pollen in the air. This means more people may get hay fever, or their symptoms may worsen. In addition, people are exposed to more UV radiation. This can be, for example, because there are more sun hours, there are fewer clouds and people are outside more in sunny weather. This increases the risk of skin cancer.

In addition, certain infectious diseases, such as Legionnaires' disease, are now more common due to climate change. The *Legionella* bacteria which causes this disease multiplies in warm water and can be inhaled through mist, for example, when it rains hard after a warm and dry period. Furthermore, ticks are active for a longer period of time, increasing the likelihood of getting Lyme disease. Moreover, climate change can have a negative effect on mental health, due to the threat it poses and to experiencing extreme weather.

RIVM collated the existing knowledge at the request of PBL Netherlands Environmental Assessment Agency. PBL is bringing together the knowledge as part of the update of the National Climate Adaptation

Strategy (NAS). In the coming years, PBL will provide an overview of the future consequences of climate change.

Keywords: climate change, health effects, heat, air quality, mental health, UV radiation, allergies, infectious diseases

Publiekssamenvatting

Gezondheidseffecten van klimaatverandering

Actualisatie van de huidige klimaatrisico's voor gezondheid

Het klimaat verandert wereldwijd, en ook in Nederland. De gemiddelde temperatuur is de afgelopen eeuw gestegen. Er is meer neerslag, meer droogte en er komen vaker zomerse dagen voor (boven de 25 graden Celsius). Het RIVM heeft de gevolgen van klimaatverandering voor onze gezondheid in de afgelopen 30 jaar (1991-2020) in kaart gebracht. Er zijn nu al grote gevolgen voor de gezondheid te zien. Deze effecten zullen naar verwachting toenemen.

Dit onderzoek focust zich op de effecten op de gezondheid van hitte, UV-straling, luchtkwaliteit, (pollen)allergieën en infectieziekten door klimaatverandering. Ook mentale gezondheidsgevolgen zijn meegenomen. Het blijkt mogelijk te zijn om aan te geven dát klimaatverandering de gezondheid verslechtert en op welke manier. Maar de mate waarin dat gebeurt is vaak nog niet aan te geven omdat ook andere oorzaken eraan bijdragen. Meer kennis is nodig om de impact van klimaatverandering beter in beeld te krijgen en goede adviezen voor beleid te kunnen maken die de gezondheid beschermen.

Het best onderbouwde effect van klimaatverandering op gezondheid is het aantal extra sterfgevallen door de hogere gemiddelde jaartemperatuur: gemiddeld 250 doden per jaar. Door klimaatverandering zijn er onder andere meer warme dagen (boven de 20 graden). Ook komen er meer hittegolven voor, die langer duren en heter zijn. Hierdoor sterven meer mensen dan normaal.

Hitte en droogte gaan vaak samen met veel pollen in de lucht en hoge concentraties ozon (zomersmog). Hierdoor kunnen mensen het benauwd krijgen, zeker als zij al aandoeningen aan de luchtwegen hebben. Het groeiseizoen duurt langer en er zijn meer pollen in de lucht. Meer mensen kunnen hooikoorts krijgen of hun klachten kunnen erger worden. Daarnaast staan mensen om verschillende redenen aan meer UV-straling bloot. Bijvoorbeeld omdat de zon meer uren schijnt, er minder wolken zijn en mensen meer buiten zijn met zonnig weer. Hierdoor is de kans op huidkanker groter.

Verder komen bepaalde infectieziekten, zoals legionellose, door klimaatverandering nu vaker voor. De Legionella-bacterie, die deze ziekte veroorzaakt, vermeerdert zich in warm water en kan via nevel worden ingeademd. Bijvoorbeeld als het na een warme en droge periode hard regent. Verder zijn teken een langere periode in het jaar actief, waardoor de kans om de ziekte van Lyme te krijgen groter is geworden. Daarnaast kan klimaatverandering een negatief effect hebben op de mentale gezondheid door de dreiging die ervan uitgaat en ervaringen met extreem weer.

Het RIVM heeft de bestaande kennis verzameld op verzoek van het Planbureau voor de Leefomgeving (PBL). Het PBL verzamelt kennis over de gevolgen van klimaatverandering voor de vernieuwing van de Nationale Adaptatie Strategie (NAS). Het PBL brengt de komende jaren ook de toekomstige gevolgen van klimaatverandering in beeld.

Kernwoorden: klimaatverandering, gezondheidseffecten, hitte, luchtkwaliteit, mentale gezondheid, UV-straling, allergieën, infectieziekten

Contents

Summary

The climate is changing worldwide, and therefore also in the Netherlands. Average temperatures have risen over the past century, there is more precipitation and more drought, and very hot days are more frequent. Climate change affects our health. As part of the review of the National Climate Adaptation Strategy (NAS), PBL is looking into the effects of climate change together with other knowledge institutes. RIVM is mapping out the health effects. This is a new analysis (recalibration/update) of the health effects of climate change over the period 1991–2020. This new analysis of the health effects of climate change provides a basis for policy and prioritisation of the most urgent risks and monitoring of long-term risks.

Six climate-related health topics were analysed for the update: heat, air quality, mental health, UV radiation, (pollen) allergies and infectious diseases.

PBL gives an update of the effects of climate change on several sectors, such as: water, nature and agriculture. To compare the results, a format in the form of a fact sheet was created by PBL. Each climate-related health topic includes an elaboration of:

- climate risk analysis, consisting of the climate threat, secondary effects, exposure, susceptibility, adaptive capacity, impact and cascading effects;
- based on the climate risk analysis, impacts on people and culture, nature and environment and the economy are translated into a final impact. The likelihood of these impacts was then described, as well as possible wildcards ('black swans') and tipping points;
- context, consisting of the governance context, coherence with other transitions and policies, international aspects, maladaptation and/or lock-ins, leads for adaptation policies and equity;
- guarantee of quality, consisting of transparency, aggregation and delineation, knowledge gaps, uncertainty, reliability and expert assessment.

For the six climate-related health topics, all these aspects have been fleshed out as best as possible. The main health risks for the topics were identified as follows:

1. Due to climate change, average temperatures are rising and the Netherlands is experiencing more frequent and more intense heat. Both heatwaves and increases in mean annual temperatures lead to burden of disease and mortality. Cold-related burden of disease and mortality will decrease according to current insights.
2. Weather conditions that can negatively affect air quality, such as heatwaves with low wind, drought and a high UV index, are more common with climate change. This results in high ozone formation (summer smog) and particulate matter lingering in the air. Consequently, people experience (additional) health

problems. At the same time, the overall health risk is decreasing because of improvements in air quality due to climate mitigation measures.
3. Experiencing acute events (extreme weather events), subacute events (facing long periods of drought) or the overall threat of climate change can lead to mental health problems. This manifests in the form of anxiety, stress and depression, among other things.
4. Due to climate change, the Netherlands is experiencing higher temperatures and more summer days with temperatures of at least 25 °C and less cloud cover. This, together with a thinner ozone layer and an improvement in overall air quality, is causing an increase in UV radiation reaching the Earth's surface. With an increasing number of days with temperatures of at least 20 °C, more outdoor recreation is expected, causing an increase in UV exposure. UV radiation is considered the main risk factor for developing skin cancer.
5. Due to climate change, the pollen season starts earlier and lasts longer, pollen concentrations are increasing and pollen may become allergenic. The Dutch climate is becoming more suitable for the presence of non-native plant species that produce allergenic pollen. As a result, hay fever symptoms in existing patients will last longer and/or worsen, and it is likely that more people will develop hay fever.
6. Certain infectious diseases, such as those caused by *Legionella* and *Vibrio* bacteria, are more common now than in previous years due to climate change. For example, because periods of drought are more often followed by heavy rainfall, there are more pneumonia cases. In extremely hot summers, wound infections are more common due to higher seawater temperatures. Furthermore, ticks are active for a longer period of time, increasing the likelihood of getting Lyme disease.

Negative health effects are already occurring for all topics.
The magnitude of these health effects is expressed as a final impact: few affected persons/deaths (low final impact) to many affected persons/deaths (high final impact). In many cases, the magnitude of the contribution of climate change to health effects cannot yet be accurately calculated. With the knowledge available, a final impact has been estimated. For heat, air quality, mental health, UV radiation and hay fever, the final impact on humans from climate change is estimated to be high. For each infectious disease analysed for this report, the final impact on humans varies and is estimated from low to medium or is unknown. For many other infectious diseases, no estimate has been made in this report as yet. Not all people are equally affected.
For each topic, there are different groups that are particularly vulnerable to the health effects of climate change.

Reliable data on the risk of health effects from climate change varies for each topic. Reliability is often high when it comes to routes of exposure and health effects. There is often consensus on the link between climate change and health effects. When it comes to the share of climate change and the size of the share, certainty and reliability vary for each topic.

To monitor health effects, relevant indicators that are already being measured have been mentioned.

Many knowledge gaps still exist, and more knowledge development is needed to properly assess how climate change affects health. To start researching the actual impact of climate change on health, it is important to properly monitor the aforementioned indicators and possibly develop new ones. Additional focus should be placed on developing more knowledge on the cumulative effects that can occur in conditions involving heat, air quality and pollen at the same time. There should also be a focus on what climate adaptation policies can be applied to reduce negative health effects.

A follow-up study will look at the expected future health effects of climate change.

1 Introduction

1.1 Background

The climate is changing, and the effects of climate change have been increasingly seen and felt in the Netherlands in recent years. Climate change poses risks across all sectors, and those risks will only increase if the Paris targets are not met. To understand what climate risks are involved, PBL Netherlands Environmental Assessment Agency conducted the first Dutch climate risk analysis in 2015 (PBL, 2015). In 2021, departments of ministries, under the banner of the Directors' Consultation on National Climate Adaptation Strategy (DO NAS), jointly decided to commission another climate risk analysis (Witmer et al., 2023). The results provide knowledge for a revision of the National Climate Adaptation Strategy (NAS). After all, since the previous risk analysis, climate change has continued and more knowledge has been developed.

Based on the sectors chosen by various ministries, PBL asked several knowledge institutes to produce a new analysis of the main climate risks. PBL is giving an update of the effects of climate change on several sectors, such as: water, nature and agriculture. It asked various knowledge institutes to provide input for this purpose. RIVM was asked to map the health effects of climate change over the past 30 years (1991–2020). A follow-up study will look at the expected health effects due to climate change in the future, and this is therefore not addressed in this report. In 2014, RIVM carried out the previous assessment of the health effects of climate change (Wuijts et al., 2014). RIVM, together with the Dutch Ministry of Health, Welfare and Sport and PBL, has identified six topics where the greatest health effects are expected. This was shown in previous research (Huynen et al., 2019; Hall et al., 2021; Van der Ree et al., 2022). This study analyses the health effects of six climate-related topics: heat, air quality, mental health, UV radiation, pollen allergies and infectious diseases.

1.2 Method

To be able to compare the sub-studies of the various knowledge institutes and to allow for the analysis to be repeated in the future, PBL has drawn up a methodology for developing the analysis (Witmer et al., 2023). The methodology elaborated herein is based on the recent ISO guideline 14 091 for the analysis of climate-related vulnerabilities, risks and impacts. ISO guideline 14 091 describes how to deal with this based on a systematic approach in a consistent and transparent way, working from coarse (conceptual, narrative) to fine (quantitative calculation indicators).

ISO 14 091 uses a sector, company or area as a starting point for a risk analysis. A sector or policy sector is defined as a grouping of similar societal functions that are approached as a whole from a policy perspective and generate a specific need (for space or otherwise): freshwater availability, environment/environmental quality, health and well-being (Witmer et al., 2023). This is used as a basis for an assessment of the climate threats to this system and the associated risks. Three impact categories are used for the risks: people and culture, nature and environment, and the economy.

For each climate-related health topic, the current health effects (1991–2020) were analysed according to a fixed fact sheet prepared by PBL. For comparison with other sectors, the structure of PBL's fact sheet was followed. For each climate-related health topic, an analysis was made according to the list in Text Box 1. The definitions are from PBL (Witmer et al., 2023).

Text Box 1 Terms and definitions in the PBL fact sheets

The following text describes the brief definitions of the terms used in the fact sheets prepared by PBL. Full definitions can be found in Witmer et al. (2013) or have been provided by PBL to the knowledge institutes.

Sector

A sector or policy sector is defined as a grouping of similar societal functions that are approached as a whole from a policy perspective and generate a specific need (for space or otherwise): freshwater availability, environment/environmental quality, health and well-being.

Topic (this report specifically)

In this report, 'topic' means one of the climate-related health topics: heat, air quality, mental health, UV radiation, pollen allergies and infectious diseases.

Climate threat

The possible occurrence of a physical, climatic or weather-related phenomenon that has the potential to cause damage.

Options:

- warmer weather;
- wetter weather;
- dryer weather;
- other weather;
- sea levels rising;
- CO_2 levels in the air increasing.

Secondary effects

For example, effects on the soil, water and air systems due to the climate threat(s) or effects that significantly increase the impact of the climate threat.

Exposure

This refers to the presence of something valuable, such as people, livelihood opportunities, species, ecosystems, infrastructure or economic, social or cultural interests, that may be endangered by a climate threat.

Susceptibility

The extent to which a system is negatively or positively affected by climate change.

Adaptive capacity
The capacity of systems, institutions, people or organisms to adapt to potential harm, take advantage of opportunities or respond to consequences.

Impact
In the context of climate change, 'impact' is defined as the consequences for natural and human systems of extreme weather events or creeping climate change.

Cascade effects
Impacts that directly or indirectly affect one sector or another and increase the final impact or pose a new risk.

Final impact: people and culture
Options:
- low: < 10,000 persons affected, 0–10 seriously injured/dead;
- medium: 10,000–100,000 persons affected, 10–100 seriously injured/dead;
- high: > 100,000 persons affected, > 100 seriously injured/dead.

Final risk: economy
Options:
- low: < €100 million;
- medium: €100 million–€1 billion;
- high: > €1 billion.

Likelihood
Likelihood is the statistical probability or plausibility that a climate threat and/or consequence of a climate threat will occur. Whether there is a risk and the extent of it depends on the nature, magnitude, intensity and timing of the climate event, combined with the exposure and vulnerability of the system.
Frequency:
- less than once every 1,000 years;
- once every 1,000 years to once every 100 years;
- once every 100 years to once every 10 years;
- once every 10 years to once a year;
- once a year or more often.

Wildcards (‘black swans’) & tipping points
Wildcards or 'black swans' are defined as an unpredictable event beyond normal expectations that has an extreme impact. Tipping points are risks with uncertain and/or irreversible potential impacts and risks due to creeping developments, where a critical threshold may be crossed with irreversible impacts or impacts that are very difficult to reverse, leading to undesirable situations.

Administrative situation
Every sector or policy sector involves government and private parties, steering parties, institutions, research institutions, policies, strategies, regulations, laws, norms, standards and funding.

Coherence with other transitions and policies
It is important to assess, in addition to climate change, social developments affecting climate risks. These include aspects/developments affecting the climate threat, exposure, susceptibility, adaptive capacity, possibilities and impossibilities for adaptation, and cascading effects.

International aspects
Issues related to climate change on an international scale are also important.

Maladaptation/lock-ins
An adaptation measure that unintentionally increases rather than decreases climate risk, and lock-ins by impending plans and activities with long-lasting impacts and impacts that are difficult to reverse, such as infrastructure and building construction.

Starting points for adaptation policy
What are the opportunities to develop adaptation policies/links to other policies/barriers.

Equity
Describes vulnerable or highly vulnerable groups, regions and/or systems with high exposure, susceptibility and/or impact due to climate risks and/or adaptation measures, creating/increasing inequality.

Transparency, aggregation and delineation
How was the analysis carried out? What quantitative and/or qualitative data/models were used – what was the delineation?
To this end, PBL has produced a PBL aggregation guide (version 29.8.2023).

Knowledge gaps
The gaps in knowledge as a result of which the analysis of the risk (climate threat, exposure, susceptibility, adaptive capacity, impact, final impacts and likelihood) could ultimately be different than currently assumed.

Uncertainty and reliability
Reliability is defined as: ‘the validity of a finding based on the type, quantity, quality and consistency of the scientific evidence (e.g. understanding underlying mechanism(s), theory, data, models, expert assessment, et cetera) and the degree of consensus’.

If there is sufficient evidence with a high degree of reliability, then the certainty of a conclusion, assertion or finding can be quantified. The classification is further specified in Appendix 1.

Expert assessment
For an expert assessment, using available quantitative data (on the climate threat, exposure, susceptibility and/or adaptive capacity) and qualitative descriptions, climate events and situations will be outlined

whose potential final risks on people and culture, nature and environment and the economy are estimated.
To this end, PBL has produced a PBL Expert Assessment Guide (version 14.6.2023).

In addition to the terms in Text Box 1, the indicators available to monitor climate risk are subsequently listed for each topic. Where possible, quantitative information is given; otherwise, qualitative information is given. This includes a special focus on high-risk groups due to exposure and susceptibility.

DPSEEA
Health as a sector is about healthcare facilities, while the question for RIVM is to analyse the health risks of climate change for humans. RIVM has therefore used a slightly different method than PBL's methodology and describes the health effects based on six climate-related health topics. In doing so, it adheres as much as possible to PBL's format in the fact sheets. As a basis for completing the fact sheets, RIVM has used a previously developed DPSEEA (Drivers, Pressures, State, Exposures/Experiences, Health & Wellbeing Effects (and Actions)) model (Text Box 2 and Figure 1.1), showing a visual representation of the interrelationships around climate change and health. The DPSEEA provides a framework for assessing the risks of climate change on health.

Text Box 2 The DPSEEA model (RIVM expert: E.F. Hall)
The DPSEEA (Driving Force-Pressure-State-Exposure-Effect-Action) model is a conceptual model developed by Corvalán et al. (1999) to understand the complex relationships between the environment and human health and identify possible actions to protect and promote health. Actions can target different points in the chain between Driving force-Pressure-State-Exposure-Effect, e.g. measures aimed at source control, reducing the concentrations of a pollutant in the environment or reducing exposure. The DPSEEA model is used, among others, to develop environmental health indicators (WHO, 2004) and was identified by Hambling et al. (2011) as the most suitable model for developing environmental health indicators related to climate change.

Within the RIVM Strategic Programme project 'Healthier Climate', we used the model to map the health effects of climate change and to identify potential indicators of these effects. Several iterations of the model have emerged in recent years. We chose to use the mDPSEEA (modified DPSEEA) because it incorporates contextual factors that mediate the relationship between exposure and effect (Morris et al., 2006). These include factors that contribute to the vulnerability or increased exposure of different populations, such as socio-economic factors, demographics or behaviour.

A first version of the model (without actions) was developed and presented to a broad group of experts during an expert session. The next version was made based on the input collected. After a second round of comments, the model below was created; see Figure 1.1.

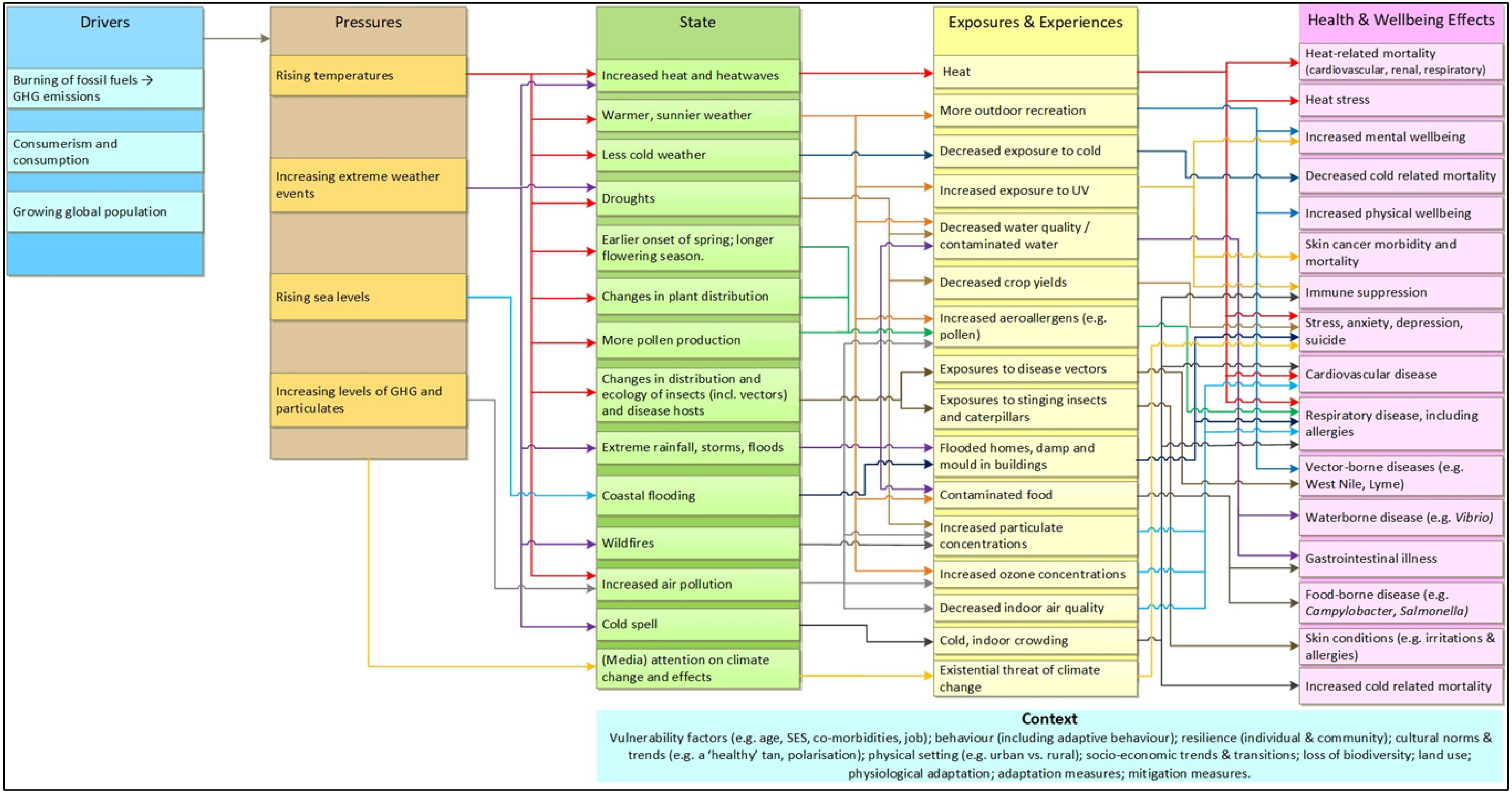


Figure 1.1 The DPSEEA model (E.F. Hall)

Final impact on people and affected persons
For the climate-relevant health topics, the final impact for people has been interpreted as described below.

The final impact for people is based on three categories (Witmer et al., 2023):
- low: < 10,000 persons affected, 0–10 seriously injured/dead;
- medium: 10,000–100,000 persons affected, 10–100 seriously injured/dead;
- high: > 100,000 persons affected, > 100 seriously injured/dead.

The definition of persons affected, seriously injured and dead is based on the impact criterion according to the Risk Assessment Guidance for the Government-wide Risk Assessment National Security (ANV, 2022a). In terms of health effects, a broad interpretation can be given to an affected person. Is a person considered affected when they have to be hospitalised due to heat-related symptoms? Or is a person also considered affected if they had a poor night's sleep due to the heat and cannot concentrate on work the next day? Even with hay fever, an affected person can be defined as broadly as someone who goes to the emergency room because of respiratory symptoms or someone who sits at home on the sofa with symptoms similar to a cold. For an affected person, PBL employs the impact criterion 2.3, physical suffering due to a lack of basic necessities of life (ANV, 2022a). These basic necessities include lack of warmth, hygiene, drinking, food and acute healthcare. The severity also depends on how long a person has been affected. In addition, PBL uses 'non-serious physical and/or mental health problems'. 'Non-serious physical health problems' is still a broad concept. A definition of 'affected person' is given for each climate-related health topic.

Final risk for the economy
The final risk for the economy can be very broadly defined when it comes to health effects. This report has focused on the information available on direct costs, e.g. care and medication costs, monetised years of life lost and costs of work loss. Information on this is not available for all climate-related topics. This is often based on costs that have been assessed once or are derived from healthcare costs that are already being incurred now, independently of the impact of climate change. Therefore, the interpretation of the final risk for the economy is not complete, but it provides an estimate.

This report builds on previous reports describing the impact of climate change on health and what knowledge gaps exist that are needed to make responsible and sustainable policy decisions in this area (e.g. Huynen et al., 2019; Hall et al., 2021; Van der Ree et al., 2022). During the development of the fact sheets, regular coordination took place with PBL and the other knowledge institutes involved in the risk analysis. There was also an expert session between PBL and RIVM experts to determine the uncertainties and reliability for each climate-related health topic.

1.3 Out of scope

There are more climate-related health topics than those detailed for the purpose of this report. For instance, there are also health risks related to safety, such as flood risks from the sea and rivers. Effects on nature, such as loss of biodiversity, also affect health. And the list of examples goes on. For the purpose of this report, this is out of scope. In part, the analysis of these topics is reflected in the analysis done by the other knowledge institutes.

Final impact for culture and nature and the environment
Cultural damage is beyond the scope of the RIVM analysis of health impacts of climate change. There is no direct impact on health due to climate change because of impact on culture. In addition, climate change has a clear impact on nature and the environment. This impact on nature and the environment subsequently also has an impact on human health. For example, climate change is causing damage to nature, resulting in loss of biodiversity and impairing ecosystem resilience. All this has consequences for human health. PBL's methodology, however, reasons along a different line. That methodology focuses on whether the direct health effects of climate change affect nature and the environment. For all topics, an increase in healthcare and use of medication affects nature and the environment. Examples are the use of raw materials, which has an impact on nature and the environment, but also medicine residues that end up in water, including potable water. Using nature for recreation and physical activities to improve mental and other health is also a direct consequence of health effects on nature and the environment. As these are indirect effects and the share of climate change is very difficult to determine, assessing a final impact of health effects on nature and the environment is beyond the scope of this study.

Adaptation measures also have an impact on health. Where logical, this has been mentioned, but this report does not provide a full analysis of the health risks or health opportunities of adaptation measures. Health risks also exist when it comes to mitigation measures (Van der Ree et al., 2019; Kelfkens et al., 2020). This, too, is beyond the scope of this report.

The full impact of climate change on the healthcare sector was not considered for the purpose of this report. However, a brief analysis has been made for climate resilience of the healthcare sector in case of extreme weather. This can be found in Appendix 2.

1.4 Reading guide

This report starts with a general chapter on the health effects of climate change. Fact sheets are then presented for six climate-related health topics.

The fact sheets start with the topic of heat, followed by the air quality fact sheet, the mental health fact sheet and a UV radiation fact sheet. Finally, there are the pollen allergy fact sheet and the infectious diseases fact sheet. The corresponding references can be found for each fact sheet. The overview of final impacts shows the key findings from the fact sheets.

2 Health effects of climate change

2.1 Introduction

The conclusions of several internationally recognised institutions are clear. The Intergovernmental Panel on Climate Change (IPCC) concludes[1] that '*Climate Change is a threat to human well-being and planetary health*', and the World Health Organisation (WHO) concludes[2] that '*Climate change is the single biggest health threat facing humanity, and health professionals worldwide are already responding to the health harms caused by this unfolding crisis*'. Climate change is the biggest threat to human health and has major implications worldwide. Figure 2.1 shows the impact of climate change on health and safety (Hall et al., 2021).

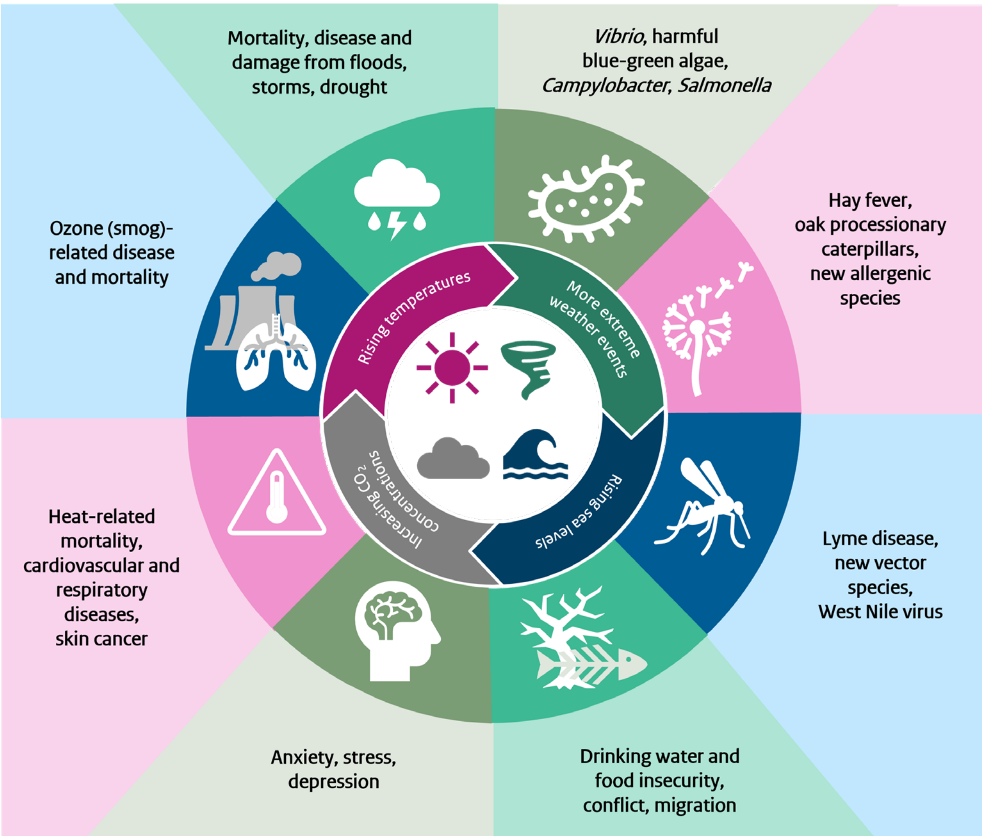


Figure 2.1 Effects of climate change on health and safety (Hall et al., 2021; figure is adapted from G. Luber, Centers for Disease Control and Prevention).[3]

The negative health effects of climate change are also visible in the Netherlands, and we can see an increase in extreme weather events. Temperatures first thought impossible by meteorologists in the Netherlands are now being reached, peaking at 40.7 °C in Gilze en Rijen in 2019. At the same time, the demand for drinking water increases in

[1] https://www.ipcc.ch/report/ar6/syr/resources/spm-headline-statements/
[2] https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
[3] https://www.cdc.gov/climateandhealth/effects/default.htm

the summer while supply decreases due to drought (Leerdam et al., 2023).

As shown in Figure 2.1, climate change can result in multiple negative health effects. This report describes current climate risks in six fact sheets: heat, air quality, mental health, UV radiation, pollen allergies and infectious diseases. The following briefly explains which climate-related health effects may occur.

Heat
Due to climate change, average temperatures are rising and the Netherlands is experiencing more frequent and more intense heat (KNMI, 2021). Both heatwaves and increases in mean annual temperatures lead to burden of disease and mortality. Accumulating effects can occur during hot periods, for example the combination of heat, drought, poor air quality and high pollen concentrations, leading to even stronger negative health effects.

Air quality
Weather conditions that can negatively affect air quality, such as heatwaves with low wind, drought and a high UV index, are more common with climate change. This results in high ozone formation (summer smog) and particulate matter lingering in the air. Consequently, people experience (additional) health problems.

Mental health
Experiencing acute events (extreme weather events), subacute events (facing long periods of drought) or the overall threat of climate change can lead to mental health problems. This manifests in the form of anxiety, stress and depression, among other things.

UV radiation
Due to climate change, the Netherlands is experiencing higher temperatures and more summer days with temperatures of at least 25 °C and less cloud cover. This, together with a thinner ozone layer and an improvement in overall air quality, is causing an increase in UV radiation reaching the Earth's surface. With an increasing number of days with temperatures of at least 20 °C, more outdoor recreation is expected, causing an increase in UV exposure. UV radiation is considered the main risk factor for developing skin cancer.

Pollen allergies
Due to climate change, the pollen season starts earlier and lasts longer, pollen concentrations are increasing and pollen may become more allergenic. The Dutch climate is becoming more suitable for the presence of non-native plant species that produce allergenic pollen. As a result, hay fever symptoms in existing patients will last longer and/or worsen, and it is likely that more people will develop hay fever.

Infectious diseases
Many pathogens (bacteria, viruses, parasites) are climate sensitive. Pathogens can be transmitted through the environment (water, air, soil) and through food, as in the case of *Campylobacter* and *Vibrio*. Transmission can also occur via vectors (mosquitoes and ticks).

Transmission and exposure are also affected by climatic factors such as temperature and humidity.

2.2 High-risk groups

At a global level, there are differences in how climate change affects people's health. But even within the Netherlands, there are health disparities, and some groups are hit harder by climate change than others. On the one hand, exposure to climate-related health threats that can cause health damage is unevenly distributed, and some groups of people are therefore at higher health risk. This may be because of where people live and work, but also because of the conditions in which they live and work. This may apply, for example, to people in poorer socio-economic positions or with physical occupations (Hall et al., 2021).
In addition, some groups of people are more susceptible to disease than the rest of the population, such as the elderly, infants and children, the chronically ill and users of medicines, alcohol and drugs (Hall et al., 2021).

Table 2.1 summarises potential high-risk groups and the climate-related topic that poses a health risk mainly for the high-risk group. What is immediately noticeable is that temperature is an important topic for all high-risk groups for both susceptibility and exposure.

Table 2.1 Overview of potential high-risk groups for exposure and for susceptibility, including the climate-related topics that pose a health risk mainly for the high-risk group (Van der Ree et al., 2022, partly adapted).

Susceptibility

High-risk group	***Climate-related topic***
Elderly people (aged 75 and over)	Temperature, infectious diseases, air quality, mental health
Infants/children	Temperature, UV radiation, infectious diseases
Young people	Mental health
Sex	Temperature, infectious diseases, mental health
Pregnant women/postnatal	Temperature, infectious diseases, mental health
Chronically ill (physical/mental)	Temperature, infectious diseases, pollen allergies, mental health
Overweight people	Temperature, air quality, infectious diseases
Users of medicines, alcohol and drugs	Temperature, UV radiation, mental health

Exposure

High-risk group	***Climate-related topic***
Residents in urban areas	Temperature, air quality
Residents in rural areas	Temperature, air quality
Working population	Temperature, UV radiation, pollen allergies
Poverty (low socio-economic position)	Temperature, UV radiation, infectious diseases, pollen allergies, air quality, mental health
Residents of unhealthy homes (moisture, poor insulation)	Temperature, infectious diseases, pollen allergies, mental health
Lonely people/social isolation	Temperature, mental health
Outdoor athletes, recreational users	Temperature, UV radiation, pollen allergies, air quality

The fact sheets detail each climate-related health topic for high-risk groups. Often, the high-risk groups fall into multiple categories, resulting in an accumulation of effects for both exposure and susceptibility, making people especially vulnerable. Consider an over-75 who lives in an urban area, in an unhealthy home and also has few contacts with others (lonely/social isolation).

3 Heat fact sheet

RIVM experts: W. Hagens, A. Versteeg – de Jong, edited by: C.D. Betgen

Health risk factors for heat are an increase in the number, duration and intensity of heatwaves and a rise in the average annual temperature.

Introduction

The effects of climate change are most noticeable in the rise in temperature. In the Netherlands, the average annual temperature has increased by more than 2 °C since 1901. Over the past 30 years, temperatures in the Netherlands have risen by an average of 1.1 °C. The Netherlands has thus warmed more than twice as fast as the global average.[4] And this rise is reflected in our weather. The number of frost days in winter is falling. Summers have more days with temperatures of at least 25 °C, and extreme temperatures are now reached, peaking at 40.7 °C in Gilze en Rijen in 2019. Changes in the jet stream are also likely to extend periods of warm weather (KNMI, 2021). Heatwaves are increasing in number, duration and intensity and are often accompanied by periods of drought.

Climate threat

The main climate threat regarding temperature-related health effects is the rising temperature. In the form of both heatwaves and average annual temperature.

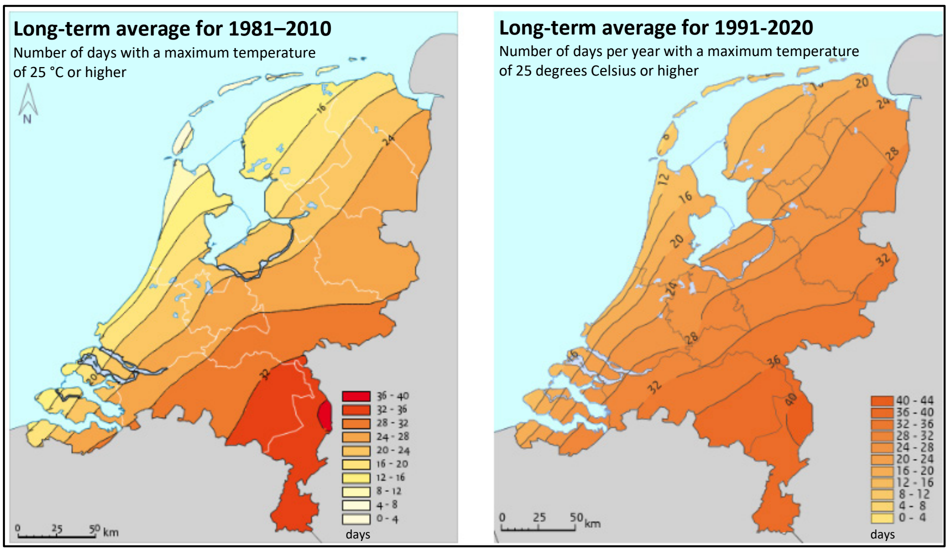


Figure 3.1 Number of days with temperatures of at least 25 °C in 1981–2010 (left) compared with 1991–2020 (right); note: the colour of the legend differs between the two reference years (source: KNMI).

[4] https://www.knmi.nl/over-het-knmi/nieuws/nederland-warmt-ruim-2-keer-zo-snel-op-als-de-rest-van-de-wereld

Heatwaves and higher average temperatures increase mortality and the burden of disease, especially among people aged 75 and over, but there is already a higher risk of heat-related conditions from the age of 65. The number of days with temperatures of at least 25 °C has increased over the past 30 years compared to the previous 30 years (Figure 3.1).

Besides an increased risk of mortality and burden of disease during periods of extreme heat, there is also a temperature-related burden of disease and mortality risk for year-round temperatures. This is related to deviations from 'optimal' daytime temperatures. In the Netherlands, over the past 30 years, the least mortality occurred at a daily average temperature of 17 degrees. If it is colder or warmer than the optimal temperature, mortality risk increases depending on age (Figure 3.2). We call this cold-related mortality and heat-related mortality. Over the period 1991–2020, 31% of heat-related mortality (about 250 deaths per year) could already be attributed to climate change due to the increase in mean annual temperatures (Vicedo-Cabrera et al., 2021).

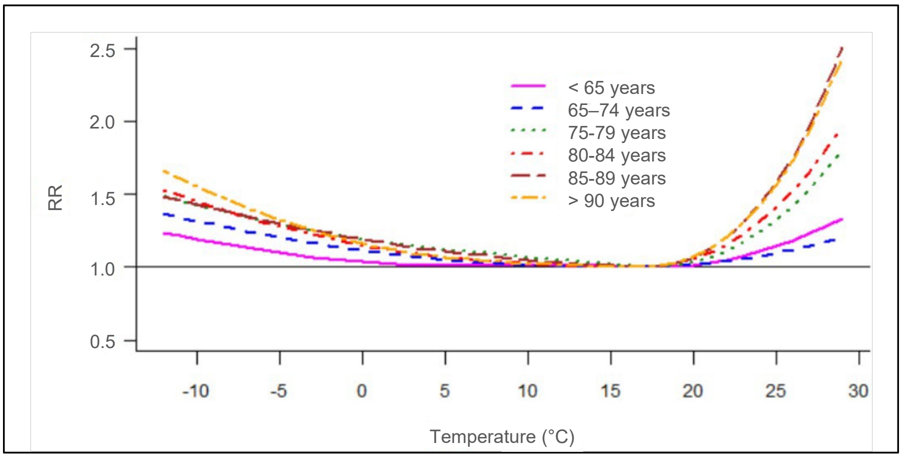


Figure 3.2 Relative mortality risk (RR) at different average temperatures and age classes in the Netherlands (source: Hall et al., 2021).

Climate change affects temperature-related mortality through warming. Current insights show that heat-related mortality will increase and cold-related mortality will decrease in the future, compared to the reference period (1991–2020). When greenhouse gas emissions are high, the increase in heat mortality is greatest (Hall et al., 2021).

For determining the impact of rising temperatures on health, air temperature is not the best indicator. The perceived temperature on hot days is a more accurate indicator of potential health effects. The perceived temperature also takes into account wind speed, humidity and solar radiation. When humidity is high, the body cannot cool down as much by evaporation (sweating) because there is already a lot of moisture in the air.

Frequency
Spring in particular has seen the largest increase in temperature over the past 30 years compared to the previous 30 years (1961–1990). The warming in spring and also in summer is partly because of an

increase in solar radiation due to a decrease in cloud cover.
Solar radiation has been increasing by 3% per decade since the 1990s, with the increase being greatest in spring, at over 4% (KNMI, 2021). Heatwaves during the 1991–2020 period took place in summer and almost never in spring (June). The frequency, duration and intensity of heatwaves are increasing due to climate change (KNMI, 2021). The chance of heatwaves in June is also increasing. Figure 3.3 shows that the three-day average temperature is increasing.

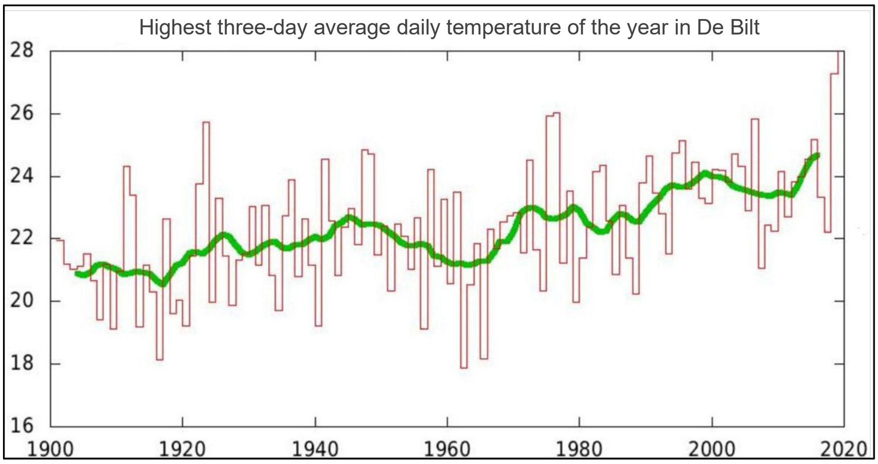


Figure 3.3 Historical development of the warmest three-day average daily temperature in De Bilt. The green line indicates the 10-year running average (source: KNMI).

Relevant indicators (source):
- Measured outdoor temperature (KNMI), showing, for example:
  - Warm days: the number of days with temperatures of at least 20 °C and consecutive days with temperatures of at least 20 °C;
  - Summer days: the number of days with temperatures of at least 25 °C;
  - Tropical nights: the number of nights with temperatures not falling below 20 °C;
  - the heatwave number (shows nuances of how extreme a heatwave period is);
  - the number of cold days;
  - the number of days deviating from the 'optimal' daily temperature;
- the perceived temperature (KNMI).

Secondary effects

Extreme weather events often involve a combination of factors.
For example, a heatwave may be accompanied by low precipitation and wind, resulting in poor air quality, with high concentrations of ozone and particulate matter in the air. The heat may also cause grasses to flower vigorously at that time, resulting in a peak in grass pollen concentrations, such as in June 2023. There is evidence that this combination of factors contributes to morbidity and excess mortality during a heatwave. Fischer et al. (2004) expected a substantial proportion of deaths now attributed to heat in the Netherlands to be

caused by ozone and, to a lesser extent, particulate matter. Moreover, Brunekreef et al. (2000) found a strong association between daily pollen concentrations and cardiovascular and respiratory mortality in the Netherlands, an association also recently found in Finland (Jaakkola et al., 2022). Climate change will increase combined exposures to heat, air pollution and pollen. More research is needed on the cause and extent of mortality and the burden of disease from combined exposures during warm periods.

The advantage of rising average temperatures is that cold-related mortality is expected to decrease in winter. Further research is needed on what exactly causes cold-related mortality (Van der Ree et al., 2022). In the Netherlands, cold-related mortality in the general population is not caused by direct exposure to low temperature (although this does pose a risk for homeless people). It is much more likely that this concerns spending more time indoors and more exposure to viruses. Due to climate change, cold-related mortality is expected to decrease in the most extreme climate scenario (Botzen et al., 2020). Hall et al. (2021) also expect heat-related mortality in the most extreme climate scenario to eventually surpass cold-related mortality. Current IPCC expectations are that we will follow a less extreme scenario.

We know how many people die in winter and how many of them die of respiratory infections. However, there is not always a clear distinction in the cause of respiratory infections (e.g. flu or a poor indoor environment). More research, even beyond climate change, is needed for this.

Exposure

In general, both indoors and outdoors, everyone is exposed to heat and a rise in the average temperature. However, there are high-risk groups that are exposed to heat a lot or are more susceptible to heat. Residents in urban areas are additionally exposed to heat because of the heat island effect. Certain occupational groups are more exposed to heat, such as outdoor workers (construction workers, green space workers) and outdoor athletes and their audience. However, people are also exposed to heat indoors, such as in buildings and homes. People in a financially vulnerable position often do not have the means to take cooling measures. Residents of old, poorly insulated homes are more exposed to heat. People who are lonely (especially the elderly) are also more exposed to heat because they often do not (or cannot) take measures to cool down (such as drinking extra fluids and cooling off in a park).

Indoor versus Outdoor

People spend about 80–90% of their time indoors. Indoor temperatures are therefore also important to consider when outdoor temperatures are high. High-risk groups such as elderly people in care homes, especially during hot days, are indoors almost 100% of the time and need to be closely monitored. If this indoor space is cooled, there is less of a health risk on hot days. Poorly insulated homes can heat up considerably during warm periods. Even properly insulated houses can heat up strongly and cannot dissipate heat quickly. This is especially true in the absence of or improper use of sunblinds and poor or absent ventilation.

As a result, it remains warm inside the house at night and after a long period of heat. During a prolonged heatwave, even well-insulated homes eventually heat up. In the absence of passive or active cooling inside the house, even well-insulated houses cannot properly release their heat in such situations. Not only houses are affected by heat. Offices, schools and childcare centres also face high indoor temperatures.

Geography
In the Netherlands, geographically speaking, we are dealing with minor average temperature differences.[5] Annual average temperatures (1991–2020) are slightly higher in the south-west of the Netherlands (11.1–11.4 °C) and are decreasing towards the north-east (9.6–9.9 °C). In summer, the north of the country has cooler average temperatures (16.2–16.5 °C), and the south-east has the warmest average temperatures (18.0–18.3 °C). There is also a geographical difference when it comes to the number of days with temperatures of at least 25 °C. On the coast, the number of days with temperatures of at least 25 °C is between 12 and 16, while in Limburg and south-east Brabant, it can go up to more than 40 days (see also Figure 3.1). KNMI indicates that, in hot summers, the number of days with temperatures of at least 25 °C along the coast can already reach 20 to 30 days. In the south, in the summer months alone, that can go up to more than 45 days with temperatures of at least 25 °C.[6]

City versus Countryside
Compared to areas and villages outside the city, a city is compact and consists of a relatively large amount of paved surface. Cities therefore heat up more than areas outside the city and retain heat for a long time (heat island effect). Vegetation (and to some extent water) has a cooling effect and lowers the temperature. Therefore, it is cooler outside the city and in small village centres. Temperatures can also vary from one district of a city to another. The temperature difference in the city versus outside the city can be as much as 8 °C (at night).

Day versus Night
The differences between the city and outside the city are mainly noticeable during the night. As cities made of stone and concrete retain heat longer, they do not cool down during hot spells at night and warm up additionally the next day. Outside the city, vegetation and fewer buildings ensure temperatures decrease during the night. In general, people living in cities are more likely to experience the health effects of heat than those outside the city. The amount of tropical nights (temperatures above 20°C) also shows a slight difference in geography. Along the coast, the nighttime temperature decline is on average the smallest and the number of tropical nights is the highest. Cities that are also located on the coast (such as The Hague) in particular will experience an additional effect of this. Increase in warm nights. Minimum temperatures of 18 degrees or more are about three times more common this century (see Figure 3.4) than they were in the second half of the previous century.[7] Tropical nights create poorer sleeping conditions, which is associated with daytime fatigue.

[5] Data based on selection in KNMI's map viewer.
[6] https://www.knmi.nl/kennis-en-datacentrum/uitleg/zomerse-dagen
[7] https://www.knmi.nl/over-het-knmi/nieuws/warme-nachten

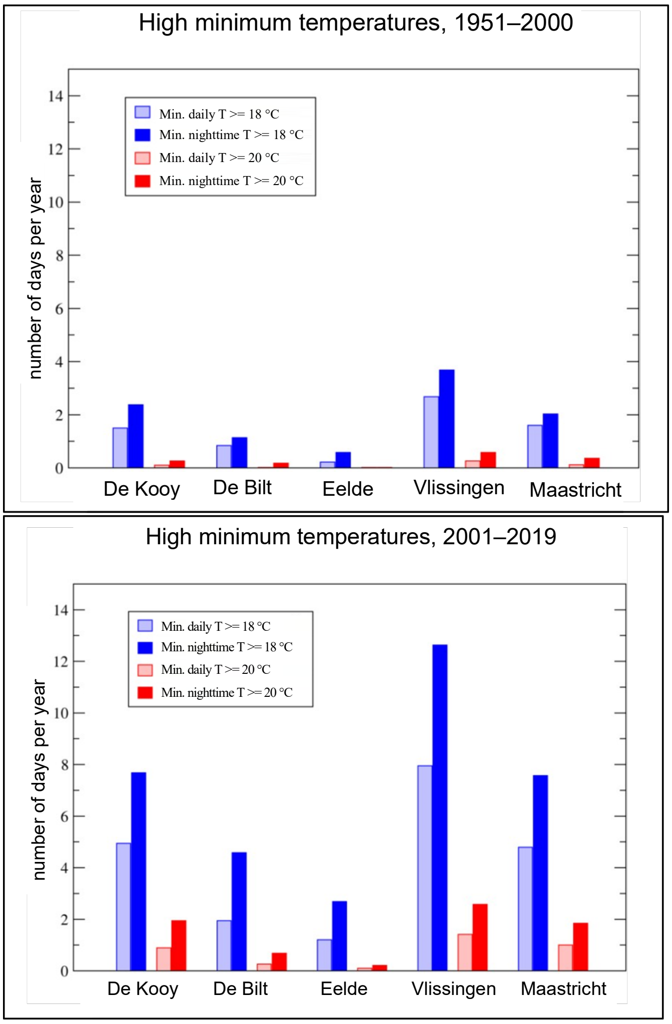


Figure 3.4 Number of days with high nighttime temperatures for five weather stations for the 1951–2000 period (top) and the 2001–2019 period (bottom) (source: KNMI).

Susceptibility

Elderly people (over 75) and babies/children are especially susceptible to heat. Both groups are less able to control body temperature. Elderly people have a reduced ability to sweat, and infants/children are unable to adapt their behaviour to heat[8] on their own (Van der Ree et al., 2022). Moreover, the incentive to drink extra fluids is reduced in elderly people/babies/children. They must be actively encouraged to drink more than usual during heat periods. Women are slightly more susceptible to heat than men because women sweat slightly less and usually have more fat, which provides extra insulation. In addition, chronically ill people, overweight people and users of medicines, alcohol and drugs are more susceptible to heat. For example, medicine can increase the risk of dehydration or impair the ability to sweat.
High-risk groups unable to adapt themselves or their environment to higher temperatures are the most vulnerable to heat stress. These include elderly people living in urban areas in nursing homes or houses that are poorly insulated.

[8] https://www.rivm.nl/ggd-richtlijn-mmk-hitte-gezondheid

Adaptive capacity

Behaviour

To avoid heat stress, it is important to stay well hydrated, take it easy and make sure the body does not heat up too much. This adaptive behaviour can help in dealing with higher temperatures. In warm countries (such as southern European countries), such behaviour is part of the culture, and people act accordingly (e.g. siesta, swimming, seeking shade and a different architectural style such as white walls and no south-facing windows). The National Heatwave Plan gives behavioural advice (see the section on administrative situation).

Adaptation is an important factor in getting people to cope with higher temperatures. There are regional differences[9] worldwide in the health effects of climate change (Zhao et al., 2021). A recent analysis found that populations are adapting to the effects of climate change such as higher temperatures. For instance, the temperature at which mortality risk is lowest moves to some extent with the development of average temperatures, but in addition, further adaptation is needed (Tobias et al., 2021). It is therefore relevant to consider what factors (such as heat period duration, nighttime temperature, demographics and so on) play a role in the relationship between temperature and the risk of health effects, and how they can contribute to adaptation.

Habitat and Housing

Many types of adaptation measures can be implemented in public spaces and around houses to bring down temperatures. Many municipalities already take this into account in their plans, but mainly with a focus on water storage. Parks in cities with lots of trees and also lots of public green spaces between and around buildings ensure lower temperatures and offer a place where people can go to cool down. Trees and pergolas with greenery provide shaded areas. Building standards have included a standard for indoor temperatures since 2021. The climate-adaptive building benchmark[10] also gives suggestions for taking temperature into account. As early as the construction phase of buildings, such as shops, the effect of shadows can be taken into account to ensure that less sunlight shines directly in. In houses, soffits, green facades and exterior blinds can also significantly reduce indoor temperatures. This greatly reduces the need to cool the indoor space with passive or active cooling technology, resulting in less heat being emitted to the outside (during the day and at night) and less energy being consumed. In extreme cases, such as in a care home with elderly people, air conditioning (set at a few degrees cooler than the outside air) may be the only way to mitigate negative health effects of heat. In the elderly, the effect of acclimatising to the outdoor temperature is not as strong as in the young.
There is no party responsible for the health of the general population when it comes to adapting to heat. For specific groups, this may be different, in full or in part. For example, as an organiser of an event in which people are participating (e.g. sports events). Similarly, a care provider in a nursing home also has a responsibility towards its clients,

[9] Regions in this case refers to the eight global regions defined by the UN: https://unstats.un.org/sdgs/report/2020/regional-groups/
[10] https://open.overheid.nl/documenten/ronl-6fc860b398612d91d66d38bbb47ed0de9bfb9071/pdf

and working conditions regulations may include agreements on heat that employers must take into account for their employees.

Relevant indicators (source):
- the number of days the National Heatwave Plan is active (RIVM);
- the percentage of green space (10x10 metres) (Atlas Leefomgeving).

Impact

Heat-related mortality and burden of disease
The body's inability to cool down is a direct consequence of high temperatures. If the ambient temperature is close to the body or skin temperature (around 35 °C–37 °C), the body cannot cool down, causing overheating. High humidity levels in the air reduce the evaporative effect of sweating, reducing the body’s ability to cool down from sweating. Direct consequences are headaches, dehydration and fainting. These consequences occur mainly in places where people exert effort in heat, such as during sports or when attending a festival.

Heatwaves lead to excess deaths. During the heatwaves in 2003 (14 days, maximum temperature of 35 °C) and 2006 (7 and 16 days, maximum temperatures of 32 °C and 35.7 °C), more than 1,000 additional people died in the Netherlands from the effects of heat (CBS, 2003) (CBS, 2006). Even following the introduction of the National Heatwave Plan, there are still excess deaths during heatwaves. For example, in the summer of 2020 (13 days, maximum temperature of 34.6 °C), heatwave mortality was 9% higher (nearly 100 more deaths) than average.

Heatwaves lead not only to excess deaths but also to illness and loss of well-being; however, more research is needed to determine the level of this burden of disease. The elderly, people with chronic diseases and young children are especially susceptible to this. In addition, such health problems are more likely to occur in urban areas.

Besides direct physical effects on health, heat also has an impact on mental health (Hall et al., 2021). Persons with a mental illness are especially vulnerable to extreme heat or heatwaves. Mullins & White (2019) found a link between an increase in temperature and an increase in suicide and emergency room visits for mental health problems for the United States. Sleep disruption is seen as an important mechanism for this. Gao et al. (2019) found in their analysis that a 1 °C increase in temperature was associated with a 1% increase in suicide cases. Links between heat and self-reported mental health problems and possible links between heat stress and aggression are also found (Hall et al., 2021).

In the Netherlands, during the heatwaves of 2003 (early June to late August) and 2006 (July), more than 1,000 extra people died from heat-related causes (CBS, 2003; CBS, 2006). Excess mortality during a heatwave depends on the vulnerability of the population. In the summer of 2018 (two heatwaves), for example, there was hardly any excess mortality, which may be because this vulnerable group had already been hit by the flu epidemic during the winter period.

There had already been a period of excess mortality in the previous winter. In contrast, in late July 2019, 400 more people died in a week from the heatwave that saw record temperatures of above 40 °C.[11]

Temperature-related mortality and burden of disease
Besides an increased risk of mortality during periods of extreme heat, there is also a temperature-related mortality risk. This is related to deviations from 'optimal' daytime temperatures.

Of all deaths in summer in the Netherlands between 1991 and 2018, 1.8% was linked to a rise in temperatures. Without an additional rise in temperatures due to global climate change, this percentage is expected to have been 1.24%. For the Netherlands, this amounts to almost 250 additional deaths per year (Vicedo-Cabrera et al., 2021).

Besides heat mortality and temperature-related mortality, relatively little is still known about the impact of heat on illness (morbidity). Research has been conducted in the Netherlands on the number of emergency admissions in relation to temperature and humidity (Loenhout et al., 2018). They found an increase in the relative risk of ending up at the emergency room with the disease classifications 'Possible heat-related diseases' (including renal failure) and 'Respiratory diseases' at higher temperatures. An additional finding was that the relative risk of one extremely hot day was found to be similar to the relative risk of several days of moderate heat. A recent study also concluded that there may be a link between exposure to high temperatures and cardiovascular and respiratory diseases (Rocque et al., 2021). Links between heat and self-reported mental health problems and possible links between heat stress and aggression are also found (Hall et al., 2021).

Relevant indicators (source):
- temperature-related mortality, modelled (RIVM);
- the number of heat-related deaths (CBS);
- possible indicator, but not yet available:
    - emergency room admissions during heat.

Cascade effects

In the Netherlands, long periods of heat are often accompanied by warm nights, disrupting sleep. This leads to fatigue and loss of concentration. This in turn affects work performance and can lead to work loss and mental health problems. In addition, warm periods are often accompanied by poor air quality (summer smog), which has health implications for people with cardiovascular diseases.

Extreme heat can lead to drought, followed by biodiversity loss and possibly more wildfires. In turn, wildfires cause poor air quality.
Soil settlement can cause cable breaks in data and telecommunication cables, affecting people's virtual accessibility. In addition, roads and rail lines dilate, creating disruptions in transport options (ANV, 2022b).

Drought caused by prolonged heat can have long-lasting effects on nature (>1 year). A dry period translates into a critical drop in

[11] https://www.cbs.nl/nl-nl/nieuws/2019/32/hogere-sterfte-tijdens-recente-hittegolf

groundwater levels. It takes a long time to replenish lowered groundwater levels. In addition, acidification and salinisation caused by drought will cause rare vegetation species to disappear. As the whole of the Netherlands is affected by drought, nature throughout the country is also affected (ANV, 2022b). This loss of biodiversity reduces the health and function of ecosystems. Moreover, it will affect their resilience and ability to absorb and withstand climate-related hazards such as drought, floods or storms.

Final impact: people

Both heatwaves and increases in average annual temperatures have an impact on health. Mortality in particular has been studied in this regard; less is known about the burden of disease caused by heat.

Heat mortality
Climate change has increased the number of heatwaves and days with temperatures of at least 20 °C and 25 °C. The contribution of climate change to heat mortality is therefore very likely. Deaths from heatwaves and heat spells vary, but over the past 30 years, the number of heat-related deaths has been high. Moreover, heat affects the entire population with various health effects, with certain susceptible groups being more strongly affected. The final impact on people due to heat is high (>100,000 persons affected and >100 deaths).

Temperature-related mortality
As mentioned earlier, no less than 31% (about 250 deaths per year) of temperature-related mortality due to temperatures above the optimum over the period 1991–2020 can be attributed to climate change due to the rise in mean annual temperatures. The final impact of a rise in average temperatures is high (>100 deaths per year).

Final risk: economy

It can be imagined that, because of the heat, nighttime temperatures are high, causing sleep quality to deteriorate. Lack of sleep affects the ability to concentrate and leads to a loss of productivity. A high temperature of itself reduces productivity. Lower productivity leads to work loss. So far, this has not been a topic of any research in the Netherlands.

Likelihood

Since measurements began in 1901, there have been 30 heatwaves in the Netherlands, about half (14) of which have been in the past 23 years. There have also been some years when there were multiple heatwaves in a single year (2006, 2008, 2018 and 2019)[12]. In the Netherlands, a heatwave therefore occurs about once a year as things stand. Mortality related to a hot period/heatwave will not occur with every heatwave but the frequency is between once every 10 years to once every year.

Due to a rise in average temperatures, mortality related to temperatures above the optimum occurs every year.

[12] https://www.knmi.nl/nederland-nu/klimatologie/lijsten/hittegolven

Wildcards & tipping points

In 2019, for the first time in the Netherlands, a temperature of more than 40°C was measured in Gilze-Rijen (37.5 °C in De Bilt). This was a serious wildcard or 'black swan' event, something that was considered virtually impossible in the Netherlands without a rise in global temperatures. The old record in De Bilt stood at 35.6 °C (1946) and was highly unlikely at the beginning of the 20th century, with a recurrence time of at least 150 years. In today's climate, around 35°C occurs once every five years.[13] The Netherlands is not well prepared for these extreme temperatures.

Administrative situation

RIVM is responsible for the National Heatwave Plan.[14] When high temperatures are expected for several days, organisations, professionals and volunteers (informal carers) involved in caring for the elderly and chronically ill are alerted to the fact that it will be warm for an extended period. How these stakeholders deal with this situation is up to the parties themselves. Information to prepare a local heat plan is also offered to municipalities in particular.[15] The National Heatwave Plan has been activated 17 times since its inception in 2007 (2023). The heatwave plan has been activated more often in the last five years (2018–2023) than in the previous five years. The operation and effectiveness of the National Heatwave Plan will be scientifically evaluated in 2024.

There are currently no standards for indoor temperatures in existing homes. However, a building standard (Tojuli) was recently (2021) set for the maximum indoor temperature for newly built homes.[16] It is not known how compliance with this design requirement is tested in practice. Temperature recommendations have, however, been set for workplaces (including schools[17] and nursing homes). This concerns working conditions regulations.[18] It is possible that the new 'National benchmark for a green climate-adaptive built environment and exploration of green standards'[19] will change the building measures to be taken to reduce indoor temperatures.

Research into how older people react and adapt to heat is being conducted in ZonMw's *Warm Aanbevolen*[20] (Warmly Recommended) project (2021–2023). From an interdisciplinary and participatory approach, the aim of the project is to draw up an operational perspective to minimise adverse temperature-related health effects, with a special focus on behavioural components and high-risk groups. Results from this project can be used to guide adaptation measures.

[13] https://www.knmi.nl/over-het-knmi/nieuws/ieder-jaar-een-verpletterend-hitterecord
[14] https://www.rivm.nl/en/heat/national-heatwave-plan
[15] https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/lokaal-hitteplan/
[16] https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/wetten-en-regels/nieuwbouw/energieprestatie-beng/indicatoren
[17] https://www.poraad.nl/nieuws-en-achtergronden/wat-te-doen-bij-extreme-warmte-op-school
[18] https://www.arboportaal.nl/onderwerpen/warmte
[19] https://www.tweedekamer.nl/kamerstukken/brieven_regering/detail?id=2023Z05065&did=2023D11915
[20] https://www.zonmw.nl/nl/onderzoek-resultaten/gezondheidsbescherming/programmas/project-detail/klimaat-en-gezondheid/warm-aanbevolen/

At present, no further legal standards have been set in terms of heat. Recommendations to reduce heat are given in the National Climate Adaptation Strategy.

Coherence with other transitions and policies

Heat is a theme within the National Climate Adaptation Strategy.
Heat is also closely related to the energy transition (indoor environment).

International aspects

There are no specific international aspects that affect the health of people in the Netherlands with regard to heat. With the exception, of course, of global commitments to stop rises in temperature.

Maladaptation and/or lock-ins

Maladaptation occurs when air conditioning is chosen for cooling the home without first implementing other measures. Outdoor blinds keep out a lot of heat. Insulation also makes heat less likely to enter the house. Smart ventilation and the use of fans can often provide sufficient cooling. And a heat pump can also cool in most cases. However, despite such measures, there may still be a need for an air conditioner, for example for vulnerable elderly people. In that case, the measures mentioned above help keep energy consumption and additional heat production by the appliance low. The use of air conditioners is increasing worldwide and is only expected to grow.[21] Cooling or heating elements can increase the risk of noise nuisance in residential areas. The possible extent of this nuisance is still unknown.

Urban densification that does not give enough consideration to green space in public areas can cause lock-ins. Densification causes an increase in temperature, which can no longer be solved with public greenery because there is no longer space for it.

Starting points for adaptation policy

In the Netherlands, the number of cool places set up for people to go to during heatwaves (like in the United States, where air-conditioned community centres are open for extended hours during heatwaves) is still low. Reducing the warming of buildings could easily be included in building standards and incentive policies for implementing heat protection measures in existing buildings. Municipalities can also take into account the creation of cool spots and walkways in public spaces in their spatial plans.

Equity

Vulnerable groups, as mentioned under susceptibility, include the elderly, babies/children, pregnant women, the chronically ill, overweight people and users of medicines, alcohol and drugs. People living in poorly insulated houses or/and in the city also feel the effects of higher temperatures faster than those in well-insulated houses and/or outside the city. There is often a combination of circumstances. People who already fall into a vulnerable group often also live in poorly insulated

[21] https://www.iea.org/reports/the-future-of-cooling

houses in the city. They often do not have the financial or other possibilities to adapt their homes to high temperatures. Also, neighbourhoods where vulnerable groups live tend to be less green, which means that, in those neighbourhoods, the temperature is higher anyway compared to the green neighbourhoods where less vulnerable people live.

It would be fair if adaptation measures (in public spaces and elsewhere) to reduce temperatures were initially applied in the neighbourhoods where the most vulnerable people live. Similarly, subsidies for making homes more sustainable and thus making their homes cooler should go to the people who cannot afford it now. This is also related to the Netherlands Scientific Council for Government Policy's (WRR; 2023) distribution of climate costs.

Transparency, aggregation and delineation

The data for determining the climate threat is based on quantitative data, measured and modelled by KNMI. Exposure data is largely based on quantitative data measured by KNMI and from published research. Information on the effect of indoor and inside-the-city versus outside-the-city exposure is partly based on qualitative research. The information on susceptibility is based on quantitative data from published research and partly on a qualitative interpretation of that data. The information on adaptive capacity is mainly qualitative data. The section on adaptation to temperature is based on quantitative published research. The impact is based on quantitative research data (mortality figures, mental health figures, partly burden of disease). Part of it is a qualitative interpretation of that data.

The final impact is partly based on quantitative data (excess mortality) and partly based on qualitative data (estimate of the number of persons affected).

The likelihood is based on quantitative data measured by KNMI and excess mortality.

Knowledge gaps

There are many knowledge gaps when it comes to heat and health effects related to climate change. Many of these knowledge gaps are described in the report by Van der Ree et al. (2022).

There is an obvious link between mortality/disease and heatwaves/rising average annual temperatures. Exactly how the link works is not yet clear. In particular, the accumulation of conditions during heatwaves (poor air quality, lots of pollen) is a major knowledge gap. It is also unclear whether and how quickly the body can adapt to rising average annual temperatures.

There is also a big knowledge gap when it comes to the link between mental health and heat. Conducting further research into this link is also important in terms of the cascade effect.

The health effect of heat exposure is largely dependent on our behaviour. This is another big knowledge gap. We have an idea of the groups that are most vulnerable to heat, but the impact on each group is not yet clear enough.

Excess mortality during a heat period gives a reasonable indication of the impact of heat on mortality. However, knowledge about the aftermath of a heat period on mortality is not yet known. The burden of disease caused by heat is also under-reported. The impact on the economy is therefore also not yet sufficiently clear.

Uncertainty and reliability

During the expert session with PBL, it was concluded that the reliability on the health effects of heat and the rise in annual mean temperatures is very high. And that consensus is virtually certain.

Expert assessment

RIVM experts are involved in research proposals as well as reports and other publications on the topic and are aware of the latest literature and studies. Both internally and externally, they are involved in various working groups and national and international collaborations on the topic. Expert judgement has therefore been used extensively for this fact sheet.

As there is much integrality in health effects between the topics, the aim was to have all topic experts (or their substitutes) present during the expert sessions. PBL also regularly attended these sessions, including the expert session to determine uncertainty and reliability.

Heat fact sheet references

ANV (2022b). Themarapportage klimaat- en natuurrampen. Analistennetwerk Nationale Veiligheid.

Botzen, W. J. W., M. L. Martinius, P. Bröde, M. A. Folkerts, P. Ignjacevic, F. Estrada, C. N. Harmsen & H. A. M. Daanen (2020). Economic valuation of climate change-induced mortality: age dependent cold and heat mortality in the Netherlands. Climatic Change (2020). 162: 545-562.

Brunekreef, Bert, Gerard Hoek, Paul Fischer, Frits Th M Spieksma (2000). Relation between airborne pollen concentrations and daily cardiovascular and respiratory-disease mortality. The Lancet Research letters. Vol 355. April 29, 2000.

CBS (2003). Ruim duizend doden extra door warme zomer https://www.cbs.nl/nl-NL/menu/themas/bevolking/publicaties/artikelen/archief/2003/2003-1275-wm.htm.

CBS (2006). Door hitte in juli duizend extra doden https://www.cbs.nl/nl-nl/nieuws/2006/35/door-hitte-in-juli-duizend-extra-doden.

CBS (2020). Tijdens hittegolf vooral meer sterfte in langdurige zorg. https://www.cbs.nl/nl-nl/nieuws/2020/35/tijdens-hittegolf-vooral-meer-sterfte-in-langdurige-zorg.

Fischer, Paul H., Bert Brunekreef, Erik Lebret, Air pollution related deaths during the 2003 heat wave in the Netherlands, Atmospheric Environment, Volume 38, Issue 8, 2004, Pages 1083-1085, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2003.11.010.

Gao, J., Cheng, Q., Duan, J., Xu, Z., Bai, L., Zhang, Y., Zhang, H., Wang, S., Zhang, Z., Su, H. (2019). Ambient temperature, sunlight duration, and suicide: A systematic review and meta-analysis. Sci Total Environ. 2019; 646: 1021-1029. DOI: 10.1016/j.scitotenv.2018.07.098

Hall, E.F., R.J.M. Maas, J. Limaheluw, C.D. Betgen (2021). Mondiaal klimaatbeleid: gezondheidswinst in Nederland bij minder klimaatverandering. RIVM-Rapport 2020-0200.

Jaakkola, Jouni J K, Simo-Pekka Kiihamäki, Simo Näyhä, Niilo R I Ryti, Timo T Hugg, Maritta S Jaakkola, Airborne pollen concentrations and daily mortality from respiratory and cardiovascular causes, European Journal of Public Health, Volume 31, Issue 4, August 2021, Pages 722–724, https://doi.org/10.1093/eurpub/ckab034.

KNMI (2021). Klimaatsignaal ’21. Hoe het klimaat in Nederland snel verandert, KNMI, De Bilt, 72 pp.

Loenhout, J.A.F. van, Delbiso, T.D., Kiriliouk, A., Rodriguez-Llanes, J.M., Segers, J. & Guha-Sapir, D. (2018). Heat and emergency room admissions in the Netherlands. BMC Public Health 18, 108. https://doi.org/10.1186/s12889-017-5021-1.

Mullins, J. and White, C. (2019). Temperature and mental health: Evidence from the spectrum of mental health outcomes. Journal of Health Economics 2019 68: 102240. DOI: 10.1016/j.jhealeco.2019.102240.

Rocque, RJ, Beaudoin C, Ndjaboue R, et al. (2021) Health effects of climate change: an overview of systematic reviews. BMJ Open 2021;11:e046333. Doi: 10.1136/bmjopen-2020-046333.

Tobías, A., Hashizume, M., Honda, Y., et al. (2021). Geographical Variations of the Minimum Mortality Temperature at a Global Scale. Environmental Epidemiology, October 2021. – Volume 5 – Issue 5 – p e169.

Van der Ree, J., C. Betgen, C. Boomsma, A. van Dijk, L. Hall, D. Houweling, J. Limaheluw, K. Rijs (2022) Plan van aanpak Onderzoeksprogramma Klimaatverandering en gezondheidseffecten. RIVM-rapport 2022-0030.

Vicedo-Cabrera, A.M., N. Scovronick, F. Sera, D. Royé, R. Schneider, A. Tobias, C. Astrom, Y. Guo, Y. Honda, D. M. Hondula, R. Abrutzky, S. Tong, M. de Sousa Zanotti Stagliorio Coelho, P. H. Nascimento Saldiva,

E. Lavigne, P. Matus Correa, N. Valdes Ortega, H. Kan, S. Osorio, J. Kyselý, A. Urban, H. Orru, E. Indermitte, J. J. K. Jaakkola, N. Ryti, M. Pascal, A. Schneider, K. Katsouyanni, E. Samoli, F. Mayvaneh, A. Entezari, P. Goodman, A. Zeka, P. Michelozzi, F. de'Donato, M. Hashizume, B. Alahmad, M. Hurtado Diaz, C. De La Cruz Valencia, A. Overcenco, D. Houthuijs, C. Ameling, S. Rao, F. Di Ruscio, G. Carrasco-Escobar, X. Seposo, S. Silva, J. Madureira, I. H. Holobaca, S. Fratianni, F. Acquaotta, H. Kim, W. Lee, C. Iniguez, B. Forsberg, M. S. Ragettli, Y.L. L. Guo, B. Y. Chen, S. Li, B. Armstrong, A. Aleman, A. Zanobetti, J.Schwartz, T. N. Dang, D. V. Dung, N. Gillett, A. Haines, M. Mengel, V. Huber & A. Gasparrini (2021). The burden of heat-related mortality attributable to recent human-induced climate change. Nature Climate Change volume 11, pages 492–500.

WRR (2023). Rechtvaardigheid in klimaatbeleid. Over de verdeling van klimaatkosten. Wetenschappelijke Raad voor het Regeringsbeleid, Den Haag, 2023.

Zhao, Q., Guo, Y., Ye, T., et al. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study (2021). The Lancet Planetary Health, 5 (7), pp. E415-e425.

4 Air quality fact sheet

RIVM expert: P. Ruyssenaars, edited by: C.D. Betgen

The health risk consists of a peak in poor air quality due to summer smog caused by an increase in temperature and drought. At the same time, the overall health risk is decreasing because of improvements in air quality due to climate mitigation measures.

Introduction

Air pollution is harmful to humans and nature and leads to premature deaths. In addition, respiratory problems and cardiovascular disease may develop and/or worsen (Health Council of the Netherlands, 2018; WHO, 2021). Air quality is determined, among other things, by the concentration of particulate matter (PM2.5 and PM10; in addition, there are indications that ultrafine particulates (PM0.1) have health effects), nitrogen oxides (NO_x) and ozone (O_3). Particulate matter and nitrogen oxides are released by industry, traffic and agriculture, among others. Ozone is formed in the lower atmosphere from a reaction between volatile organic compounds (VOCs, including methane) or nitrogen oxides under the influence of temperature and sunlight.[22] Methane is thus an important component for both climate and air quality policies.

Air quality is closely related to weather conditions. Wind causes dispersion and dilution of pollution, and precipitation causes particulate matter to rain out. Weather conditions that can negatively affect air quality are more common with climate change.[23] Examples are heatwaves with low wind, drought and a high UV index. In those situations, a lot of ozone is formed (summer smog) and particulate matter lingers in the air. Due to an often prevailing easterly wind during heatwaves, additional particulate matter from abroad enters the Netherlands (Hall et al., 2021). Poor air quality causes additional heat mortality (Hall et al., 2021). However, the exact relationship between premature mortality, heat and air quality is difficult to establish, and further research into this needs to be conducted. Another factor here is that the Dutch population is ageing, and the elderly are more vulnerable to the effects of air pollution.

European air quality standards are intended to reduce (and ultimately prevent) both the short-term and long-term effects of air pollution on health and nature. Health effects still occur below the legal standards. WHO has therefore derived health advisory values (health effects will still occur at those levels). Climate change affects air quality and therefore health (for example, the occurrence of episodes of air pollution, which are mainly short-term effects). But there is certainly also a link between climate mitigation and air quality (long-term effects), where climate action can have both positive and negative effects on air quality.

[22] https://www.rivm.nl/lucht/luchtkwaliteit-Nederland
[23] https://www.knmi.nl/over-het-knmi/nieuws/klimaat-penalty-slechtere-luchtkwaliteit-door-klimaatverandering

Climate threat

There are several mechanisms through which a changing climate impacts air quality and related health effects:

1. A rise in temperature affects atmospheric chemistry and thus the formation of ozone and particulate matter (climate change affects chemical processes in the atmosphere; for example, the processes by which secondary particulate matter is formed (organic and inorganic aerosols)).
2. A rise in temperature, in combination with air quality, affects health, although the mechanism through which this occurs is not yet well understood: for example, are extra 'heat deaths' in the summer period linked to temperature, to air quality or to both?
3. Climate change increases the duration and intensity of the pollen season. A combination of pollen exposure and episodes of air pollution can lead to an amplification of health effects.

To interpret health effects of air quality, a distinction is made between short-term effects (ranging from effects of air pollution peaks of a few hours to days) and long-term effects. For both types of effects, there is a relationship between air quality and climate change. This fact sheet mainly focuses on the climate threat from the short-term effects of ozone.

Climate change can affect weather conditions that contribute to short-term episodes (heat, low wind, high sun). The influence of climate change on atmospheric chemistry and thus on, for example, the formation of ozone and particulate matter can be seen in relation to both short-term and long-term effects.

Secondary effects

Some secondary effects of climate change on air quality:

1. Adapting the population to the effects of climate change may have effects on, for example, energy use (use of cooling and air conditioning); depending on how the energy is generated, this may lead to higher emissions of PM and NO_x and additional health impacts.
2. A tightening of climate policy aimed at achieving climate targets will impact the deployment of energy technologies and energy prices. The latter may, for example, lead to behavioural effects such as a substitution of natural gas use by biomass for space heating, which may cause nuisance from wood smoke.
3. Deployment of alternative energy technologies and the energy mix that follows from climate policy choices lead to both positive and negative impacts on air quality and health.

Natural fires due to climate change create poor air quality. Large wildfires are also becoming more common in Europe. They affected southern European countries in the summers of 2022 and 2023. Natural fires in the Netherlands and abroad can affect air quality in the Netherlands, depending on the direction of the wind. This can cause a temporary peak in air pollution that may cause people to experience more respiratory symptoms. Natural fires are discussed in more detail in a separate fact sheet produced by PBL.

Exposure

Short-term effects
Extreme weather conditions can amplify the number and intensity of episodes of poor air quality. Episodes particularly affect people with increased susceptibility to air pollution, such as those with lung diseases (asthma, COPD), the elderly and young children. People with outdoor occupations (especially those susceptible to air pollution effects) may also suffer more from exposure to air pollution than those with indoor occupations. Effects can range from respiratory problems, additional medication use and hospital visits to (premature) mortality (Health Council of the Netherlands, 2018).

Warmer weather may also cause grasses to flower vigorously at that time, resulting in a peak in grass pollen concentrations, such as in June 2023. There is evidence that this combination of factors contributes to morbidity and excess mortality during a heatwave. Fischer et al. (2004) expected a significant proportion of deaths now attributed to heat in the Netherlands to be caused by ozone and, to a lesser extent, particulate matter. Moreover, Brunekreef et al. (2000) found a strong association between daily pollen concentrations and cardiovascular and respiratory mortality in the Netherlands, an association also recently found in Finland (Jaakkola et al., 2022). More research is needed on the contribution of heat, air pollution and pollen to mortality and the burden of disease in warm periods, especially because climate change is expected to exacerbate these exposures.

The impact of climate change on the occurrence of short-term peaks is not easy to interpret. The figures below, based on the Environmental Data Compendium (EDC), show the trend of exceedances of the (eight-hour average) ozone guideline value in the Netherlands since 1990. Especially for the last few decades, no clear trend development for ozone can be derived from Figure 4.1. Figure 4.2 shows that there is a downward trend of exceedances of the information threshold set by the EU (hourly average concentration above 180 μ/m^3).

These figures are in line with the more general picture: there is a decrease in the number of peaks in air quality that can be attributed mainly to the effects of European and national air policy. However, the annual average ozone concentration has not decreased and continues to hover around 50 μg/m3 in Europe. The cause is thought to include increasing background concentrations throughout the Northern Hemisphere due to rising methane emissions in Asia and from marine shipping (Hall et al., 2021).

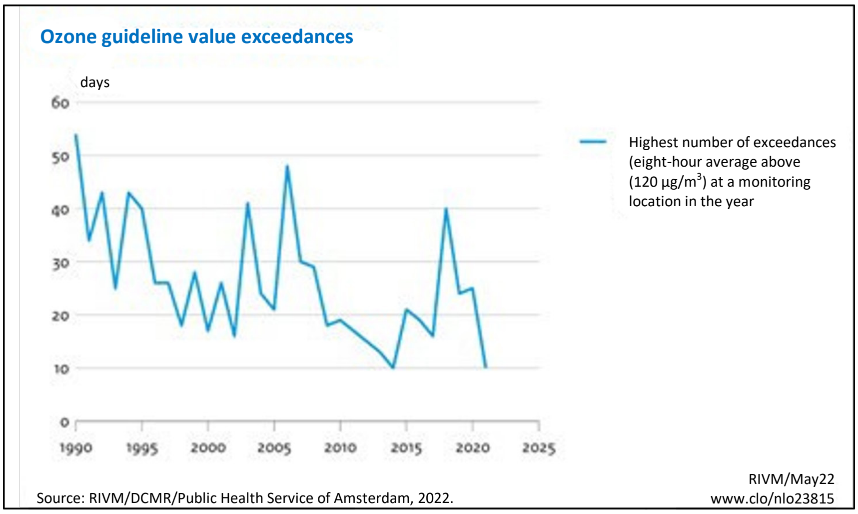


Figure 4.1 Ozone guideline value exceedances (source: CLO[24])

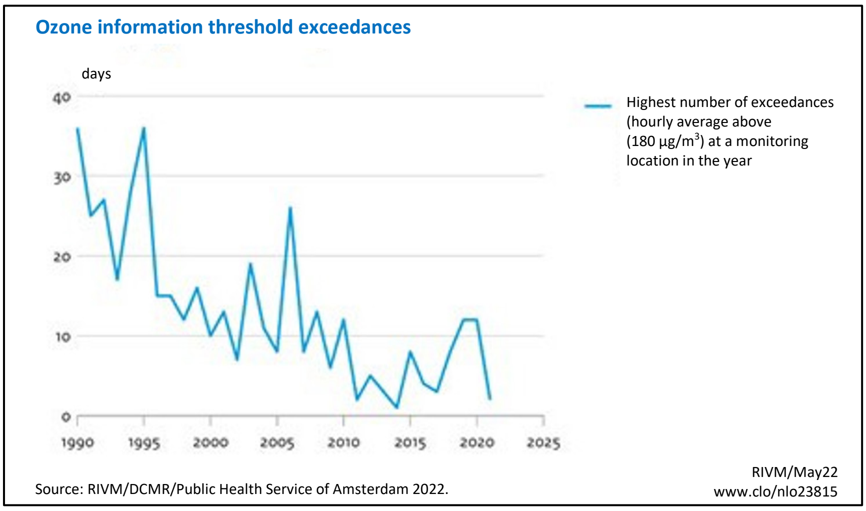


Figure 4.2 Ozone information threshold exceedances (source: CLO[25])

As already indicated, the impact of climate change on the development described above is difficult to pinpoint. Several mechanisms come into play. On the one hand, air quality is improving, as a result of which the intensity of peak and annual concentrations decreases. The policies pursued play a role here, both climate policies and European policies on ozone precursors. On the other hand, if methane background concentrations stay the same or increase, this creates more ozone, increasing ozone background levels. Finally, climate change affects chemical processes in the atmosphere that affect the formation of particulate matter (PM). Climate change affects the occurrence of episodes of poor air quality because favourable conditions for smog formation occur during days with temperatures of at least 25 °C.

Figure 4.2 shows a decreasing trend in ozone information threshold exceedances. In recent years with heatwaves in 2018, 2019 and 2020, the ozone information threshold was exceeded slightly more often

[24] https://www.clo.nl/indicatoren/nl0238-ozonconcentraties-en-volksgezondheid
[25] https://www.clo.nl/indicatoren/nl0238-ozonconcentraties-en-volksgezondheid

(up to 12 days). The number of days where exceedance occurs is still lower than in the 1990s. Over the next few years, RIVM will conduct research into the relationship between air quality and climate change.

Geography
Air quality is not the same throughout the Netherlands. Air quality (NO_x and particulate matter) depends on proximity to roads, industry and agriculture.[26] Therefore, annual average concentrations of nitrogen oxide and particulate matter are higher in the Randstad conurbation (road traffic) and in the centre of the Netherlands and in North Brabant (agriculture) than in other places. As an example, Figure 4.3 shows the annual average particulate matter (PM10) concentration.

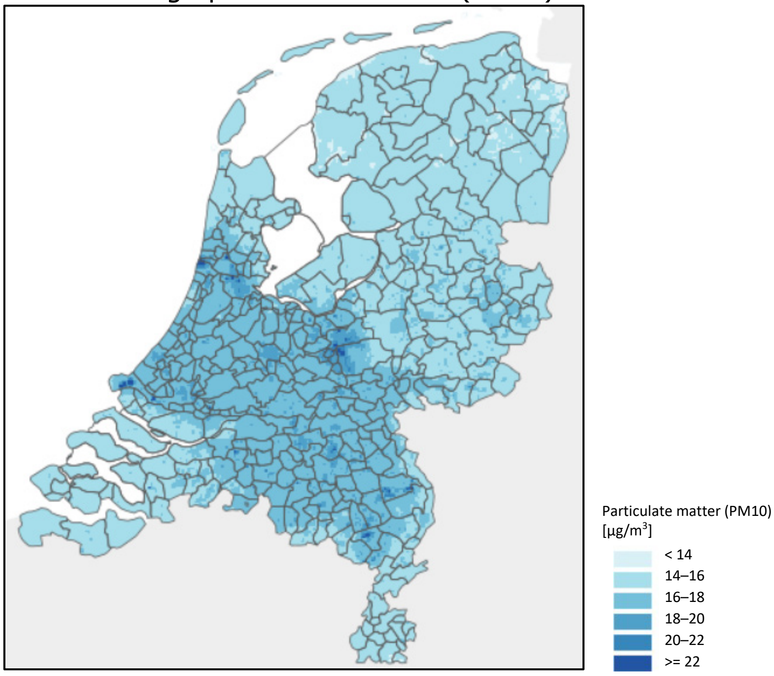


Figure 4.3 Annual average particulate matter concentration over the year 2021 (source: RIVM[27]).

In areas with – on average – relatively low annual average concentrations, exposure is also relatively lower, and there is less loss of life expectancy from air pollution. This is shown in Figure 4.4 (Ruyssenaars et al., 2021).

[26] https://data.rivm.nl/apps/gcn/
[27] https://data.rivm.nl/apps/gcn/

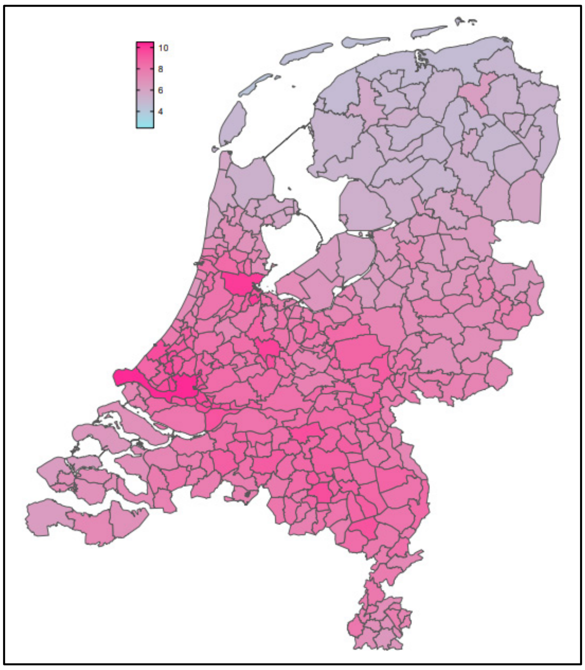


Figure 4.4 Calculated average life expectancy loss in 2016 due to combined exposure to NO2 and PM10 by municipality (source: Ruyssenaars et al., 2021)

Peak concentrations, depending on weather conditions and large-scale and other patterns of air pollution, can occur anywhere and affect everyone.

Relevant indicators (source):

- hourly and annual concentrations of particulate matter (PM10, PM2.5), nitrogen, ozone (and many other substances) (RIVM National Air Quality Monitoring Network).

Susceptibility

In terms of susceptibility to the effects of air pollution, the Health Council of the Netherlands (GR, 2018) distinguishes between several high-risk groups. In part, this concerns people who are structurally exposed to higher levels of air pollution in 'hot spots'.

In part, this also involves groups of people who are extra susceptible to the effects of air pollution (children, the elderly, people with a genetic susceptibility to air pollution (COPD, asthma) and pregnant women (with the main concern being the increased risk to the unborn child) (Bongaerts et al., 2022). And finally, people who are overweight/obese, people who smoke or have smoked and people with lower-than-average socio-economic status.[28] These 'high-susceptibles' are especially susceptible to higher peak and non-peak concentrations of air pollution; but at very high concentrations, anyone can experience symptoms.

[28] Of the last-mentioned group, EPA suspects that high susceptibility for this group is linked to higher-than-average exposure to air pollution. Fecht et al., (2015) concludes that there is a positive relationship between higher concentrations of air pollution and neighbourhoods in the Netherlands where the proportion of non-native residents is higher than 20%. In addition, according to this study, inequality for exposure to air pollution is particularly an urban problem.

Adaptive capacity

When it comes to air quality, it is important to mention mitigation policies first. Climate change is expected to increase the frequency of weather conditions in which air quality deteriorates (episodes). However, as indicated earlier, both clean air and climate policies contribute to improving air quality and reduced occurrence (and reduced intensity) of episodes of air pollution.

In addition, it was agreed in the Climate Agreement to phase out the use of fossil fuels and harmful emissions from industry and traffic. At the COP26 in Glasgow, agreements were made that will also improve air quality (e.g. methane reduction, which affects ozone concentrations).

Adaptation is possible by informing the population and providing operational perspective. RIVM developed the 'air quality index' (*luchtkwaliteitsindex*, LKI) for the Dutch Ministry of Infrastructure and Water Management in 2014,[29] informing the public about current air quality and issuing a forecast for short-term (three-day) trends. RIVM combines this with behavioural advice for susceptible groups, in case of the occurrence of episodes of air pollution. When air pollution alert thresholds set by the EU are exceeded, the entire population is actively warned, along with the suggestion that physical and other activities should take into account the level of air pollution.

When it comes to adaptation related to long-term exposure, one could also consider locating susceptible destinations where exposure is lower. The first progress measurement of the Clean Air Agreement (*Schone Lucht Akkoord*, SLA[30)] (Ruyssenaars et al., 2021) identifies regions where long-term and other exposure and health effects are relatively low. See also Figure 4.4.

Impact

The effects of air quality on health are calculated through the exposure track. This involves linking the calculated concentration of air pollutants at a relatively high level of detail (1*1 km or higher resolution) to residential buildings and (average) residential occupancy.

RIVM intends to start a project that will enable a link between long-term climate scenarios and air quality scenarios/calculation of health effects. This mainly involves the impact of climate change on atmospheric chemistry and the formation of secondary organic/inorganic aerosol (particulate matter).

In terms of health, the impact of daily or incidental exposure to particulate matter and NO_2 is greater than exposure to ozone. People can experience health problems from poor air quality in the short-term, and long-term exposure to poor air quality can cause long-term health effects. Therefore, an affected person is someone who experiences short-term or long-term symptoms. These health effects also occur below the legal standards. WHO has therefore derived air quality guidelines that are significantly lower.

[29] https://www.rivm.nl/lucht/luchtkwaliteit-Nederland
[30] https://www.schoneluchtakkoord.nl/

The average life expectancy of Dutch people is several months shorter due to inhaling unhealthy substances.[31] 2,300 premature deaths are linked to smog periods from particulate matter.[32] In 2013, 2,200 deaths were attributed to ozone.[33] Vzinfo also provides figures on endpoints other than mortality due to long-term exposure to air pollution (such as particulate matter): on an annual basis, 4,300 low birth-weight children and 11% of lung cancer cases (1,200 people).[34] These figures will be updated in the coming period based on more recent scientific insights.

In terms of economic and other valuation, the long-term effects (premature mortality and lifetime loss) count the most. The above figures are about air quality in general. It is not yet clear how much climate change has contributed to the figures over the past 30 years.

Relevant indicators (source):
The Clean Air Agreement (*Schone Lucht Akkoord*, SLA) involves calculating the impact of measures on health (Ruyssenaars et al., 2021).

The health indicator system (*gezondheidsindicator*, GHI) calculates two indicators based on combined exposure to particulate matter (PM10) and NO_2. The possibility of adding ozone to the GHI will be considered in the coming years:

- the potentially achievable (average) gain in life expectancy for a zero-year-old (in months) by reducing exposure to air pollution (Life Expectancy Loss, abbreviated as LXL). This is an 'individual' outcome measure calculated at home-address level, but it can be averaged across groups such as neighbourhoods, districts and municipalities or across the whole country. This indicator is relevant for assessing the SLA target: 50% health gains due to domestic sources;
- the number of years of life lost (YLL) for the entire Dutch population or across large groups. This indicator is suitable for determining the cost-effectiveness of policy measures and, if desired, for monetising impacts for the purpose of cost-benefit considerations. This can be done by multiplying the number of years of life lost by the average value of a year of life.

These indicators allow for:

- determining health gains at different aggregation levels (neighbourhood, district, municipality, province, national);
- assessing the contribution of different sources to health effects due to air pollution along a single yardstick (Ruyssenaars et al., 2021).

The Municipal Public Health Services (GGDs) have the GGD air quality calculation tool. The GGD calculation tool also focuses on particulate matter (PM10, PM2.5 and NO_2). For different scales (from province to neighbourhood) and from urban to rural areas, the tool can be used to calculate the effect of air quality on:

- premature mortality (30+);

[31] https://www.rivm.nl/lucht/luchtkwaliteit-Nederland
[32] https://www.vzinfo.nl/leefomgeving/luchtverontreiniging/fijn-stof
[33] https://www.vzinfo.nl/leefomgeving/luchtverontreiniging/ozon
[34] https://www.vzinfo.nl/leefomgeving/luchtverontreiniging/fijn-stof

- low birth weight;
- incidence of cardiovascular disease;
- incidence of asthma in children (0–20);
- hospitalisation due to asthma (all ages);
- hospitalisation due to COPD (all ages);
- hospitalisation due to ischaemic heart disease (40+);
- lung cancer (50+).

Indicators under development:
- increase/decrease in cardiovascular disease;
- lung cancer incidence;
- asthma in children;
- Health Adjusted Life Years (HALE).

Cascade effects

Green adaptation measures that do not take allergenic species into account may make people more susceptible to hay fever and thus more susceptible to poor air quality (Huynen et al., 2019).

Final impact on people

There is still insufficient knowledge to quantify the contribution of climate change to the health effects of air pollution. Therefore, the effects are described qualitatively in this fact sheet. The number and intensity of ozone peaks are both decreasing over the period 1991–2020, but background concentrations have increased in recent decades.

With its clean air and climate policies, the Netherlands is well on its way to reducing national/Euroregional emissions, reducing health impacts. Climate change creates conditions that worsen air quality, but policies to improve air quality reduce the health impact of ozone and ozone peaks.

During ozone peaks, despite policies, deaths still occur (2,200 in 2013). The contribution of climate change to these deaths has not yet been studied. But because air quality has a major impact on human health and climate change affects air quality, the final impact of ozone is estimated to be high (>100,000 persons affected and >100 deaths). The same applies to particulate matter and NO_x in relation to climate change and health.

Final risk: economy

The economic impact of air quality on health is high. However, the share of climate change is not known. The number of years of lost life due to air pollution can be monetised. For example, by reducing the number of years of lost life by 53,000 in 2030 compared to 2016, the SLA policy has been calculated to generate benefits of €2.6–5.8 billion (Ruyssenaars et al., 2021). Here, one year of life was valued at €50,000–€110,000, using the SCBA methodology (CE Delft, 2023). Climate policies and supplementary climate policies, with impact on PM and/or NO_x emissions, can lead to additional benefits.

The report of the baseline measurement of the SLA (Ruyssenaars et al., 2021) shows – by means of maps – the health impacts of air pollution and the calculated effects of policies (gain in life expectancy, reduction in years of life lost). The scenario calculations also include climate measures. RIVM is conducting an update, which is to be published in 2024.

The current economic impact of air pollution is high (> €1 billion). However, we cannot currently quantify the contribution of climate change to this economic impact. It can be in any of the categories low, medium or high (also depending on frequency). At the same time, the clean air and climate policies that have been deployed reduce health impacts and economic damage, so continuation of sound clean air and climate policies is needed to reduce the final impact.

Likelihood

In terms of effects of air pollution on health, a distinction is made between long-term and short-term effects. Short-term effects are mainly about the occurrence of episodes of air pollution or smog and their effects (related to particulate matter, ozone). Long-term effects involve influencing especially particulate matter formation by influencing chemical processes in the atmosphere, which can lead to higher concentrations, exposure and associated health effects.

Due to climate change, conditions for poor air quality (in summer) are expected to become more frequent. The frequency, duration and intensity of heatwaves are increasing due to climate change (KNMI, 2021). How much exactly depends on many circumstances, including the effect of national and European clean air policy on air pollution concentrations. It is precisely because of this dependence on many conditions that the impact of climate change is difficult to quantify.

The long-term health effects of air quality are likely to decrease in connection with deployed policies (including climate policies).

The likelihood of short-term health effects may increase in relation to an increase in the number of hot and dry days (summer smog). The likelihood of this occurring is already once a year or more (see Figure 4.2).

Wildcards and tipping points

A wildcard can be said to exist when the conditions for heat, drought and high pollen concentrations coincide in such a way that a period of prolonged poor air quality occurs (see secondary effects).

Administrative situation

In terms of short-term exposure, the government is obliged (based on the European Air Quality Directive) to warn the public about exceeding certain thresholds (information thresholds, alert thresholds). This task is assigned to RIVM (smog service).

There is also the Clean Air Agreement (*Schone Lucht Akkoord*, SLA).[35] The aim of the Clean Air Agreement is to permanently improve air

[35] https://www.schoneluchtakkoord.nl/default.aspx

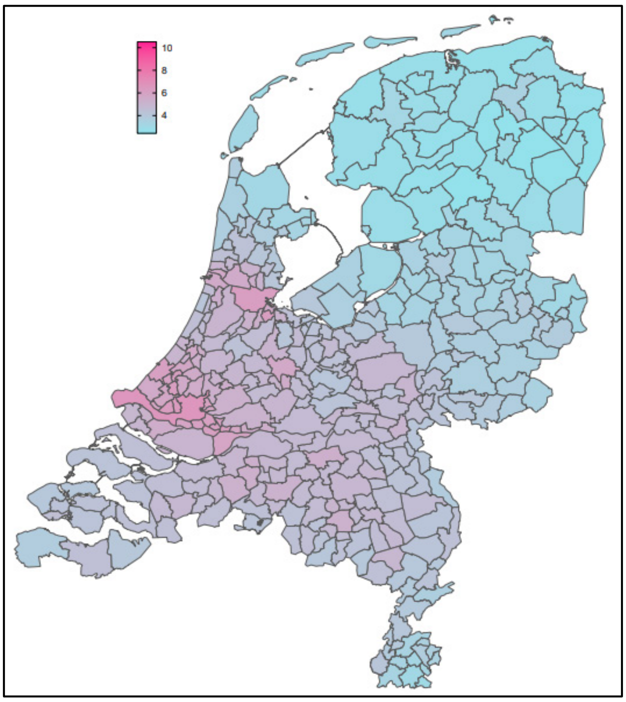
quality in the Netherlands. It is an agreement between the national Government, provinces and a large number of municipalities. Together, the participating parties aim to achieve a health gain of at least 50 percent by 2030 compared to 2016.

Through an air quality index (also a requirement under the AAQD[36]), the government continuously informs the public about air quality and how it can be characterised (ranging between good and poor, with a number of intermediate steps). The EEA additionally provides this service for all European countries. There are no clear agreements on how countries (and organisations like the EEA) interpret the air quality index. The Netherlands advocates for a harmonisation of the approach, which, for the Netherlands, should preferably focus on providing information about health risks at certain levels of air quality.

A revision of government behavioural advice to the public, which in the Netherlands is linked to the air quality index, is currently under consideration.

Coherence with other transitions and policies

The energy transition is important for improving air quality, except if this involves focusing on biomass as an alternative fuel. The use of other energy carriers such as hydrogen can also have a negative impact on air quality. When implementing the policy as calculated in the Climate and Energy Outlook for the Netherlands (*Klimaat- & Energieverkenning*, KEV), the average life expectancy is much less (Figure 4.5 compared to Figure 4.4). Agriculture and livestock policies, part of nitrogen and climate policies, can also reduce air pollution.



[36] Ambient Air Quality Directives

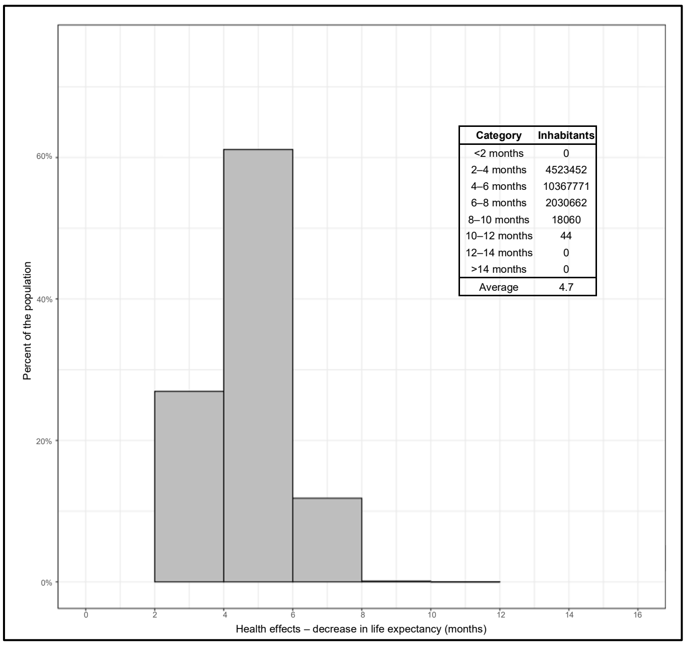


Figure 4.5 Calculated average lifetime loss in 2030 due to combined exposure to NO_2 and PM10 per municipality (first image) and per home address in the Netherlands (second image) when implementing the adopted policy (KEV) (source: Ruyssenaars et al., 2021).

An effective policy to tackle ozone requires policies at least at European or North-West European level, but it can be further supported by global agreements to further tackle methane emissions, for example, as happened at COP 26 in Glasgow.

Improved European forecasts of short-term air quality can also play a role in mitigating ozone peaks. With reliable short-term forecasts, measures on a European scale that can reduce or prevent ozone peaks can be deployed if desired. This generally only makes sense when measures are taken on a larger spatial scale and several days prior to expected ozone peaks. Tension may arise between costs (as a result of restrictions on environmentally harmful economic activities) and benefits (preventing health effects and continuing or making more room for cleaner economic activities).

An alternative to this is the current approach, where warnings are issued in the event that concentrations exceed certain concentration thresholds. For susceptible groups in particular, behavioural advice (e.g. limiting physical exertion) has been developed to reduce or prevent health effects of episodes. In the Netherlands, these are communicated through the air quality index.[37]

International aspects

Air quality in neighbouring countries affects Dutch air quality (see exposure). International clean air policy as described above also has an impact.

[37] https://www.luchtmeetnet.nl/

Maladaptation and/or lock-ins

Relying on alternative sources of energy that adversely affect air quality is a risk in the energy transition.

Starting points for adaptation policy

When it comes to air quality, many policies have already been deployed that should ensure positive health effects. Adaptation measures such as tree planting can take air quality into account by not placing trees along roads in such a way that a tunnel of poor air quality is created under them.

Equity

Earlier in this fact sheet, high-risk groups were discussed, including 'highly exposed' and 'highly susceptible' people. One of the focus points of Dutch clean air policy through the Clean Air Agreement (*Schone Lucht Akkoord*, SLA) is that everyone has a right to clean air. This focus point, on the one hand, requires a generic approach, reducing exposure for *everyone*. This will lead to the highest health benefits for the entire population.
In addition, specific areas and specific groups will require additional attention from an equity perspective. This will require a customised approach (additional measures aimed at lower exposure in specific areas, or spatial customisation creating sufficient distance between susceptible destinations and emission sources). At the point where the negative effects of climate change coincide with poorer air quality, this may be cause for additional measures to prevent combined effects.

From an equity point of view, regional and other customisation will require a political assessment, which will involve cost and benefit considerations. The SLA focuses on 'highly exposed' and 'highly susceptible' people in particular. Currently, this is mainly implemented by adhering to distance standards for susceptible destinations, but some of the policy has yet to be developed. This does involve long-term exposure.

Transparency, aggregation and delineation

The data for determining the climate threat is based on quantitative data, measured and modelled by KNMI. Exposure data is based on quantitative data – air quality measurements and modelling and literature reviews. The information on susceptibility is based on quantitative data from published research and partly qualitative (people are susceptible, but how susceptible is not always clear).
The information on adaptive capacity depends on measurements (quantitative data); based on these measurements, behavioural advice is issued, which is also ultimately substantiated with more qualitative data.

The final impact is based on model calculations and will become increasingly accurate as more scientific insights emerge. The impact of climate change on this has not yet been sufficiently studied.

Likelihood is partly based on quantitative data measured by KNMI, but it is difficult to predict because air quality depends on many factors.

Knowledge gaps

There are many knowledge gaps when it comes to the health effects of air quality in relation to climate change. Many of these knowledge gaps are described in the report by Van der Ree et al. (2022). The biggest knowledge gaps have already been identified in this fact sheet.

More insight is needed into the impact of climate change on the formation of air pollution (secondary aerosols). Also, the impact of climate change on the occurrence of weather conditions favourable to short-term peaks and the effects of climate change on those peaks themselves are relevant research topics. Finally, more research on the relationship between/coherence of premature mortality, heat stress, pollen concentrations and air pollution is relevant.

It was also mentioned earlier that RIVM will conduct research on some of the issues mentioned in the coming years.

Uncertainty and reliability

When it comes to the health effects of air quality, reliability is very high and consensus is virtually certain. There are, however, uncertainties (some of which are considerable) as to which components cause the main effects. This mainly concerns the question of which particulate matter fractions cause which effects, and hence, which policies are most effective from a health promotion point of view. For now, the scientific community says PM2.5 is a good marker for policy.

When it comes to the impact of climate change on air quality, there is still a lack of knowledge of the exact attribution of climate change on the impact of health effects due to air quality.

In principle, the climate policies deployed are delivering positive health effects through improved air quality as we stop using fossil fuels. However, there is still a lot of uncertainty as to which alternatives to fossil fuels are being deployed and to what extent they contribute to air quality degradation (for example, deployment of biofuels).

Expert assessment

RIVM experts are involved in research proposals as well as reports and other publications on the topic and are aware of the latest literature and studies. Both internally and externally, they are involved in various working groups and national and international collaborations on the topic.

As there is much integrality in health effects between the topics, the aim was to have all topic experts (or their substitutes) present during the expert sessions. PBL also regularly attended these sessions, including the expert session to determine uncertainty and reliability.

All risk assessments in this fact sheet are based on expert judgement, as the relationship between climate change, air quality and health effects can be reasoned but remains difficult to quantify.

Air quality fact sheet references

Roeffaers, Marcel Ameloot, Paul A Fowler, Tim S Nawrot (2022). Maternal exposure to ambient black carbon particles and their presence in maternal and fetal circulation and organs: an analysis of two independent population-based observational studies. The Lancet Planetary Health, Volume 6, Issue 10, 2022, Pages e804-e811, ISSN 2542-5196, https://doi.org/10.1016/S2542-5196(22)00200-5.

Brunekreef, Bert, Gerard Hoek, Paul Fischer, Frits Th M Spieksma (2000). Relation between airborne pollen concentrations and daily cardiovascular and respiratory-disease mortality. The Lancet Research letters. Vol 355. April 29, 2000.

Buijsman, E. (2011) Smog de maat genomen. Een terugblik op smog in Nederland, 1960-2010. LUVO reeks nummer 12

CE Delft (2023). Handboek Milieuprijzen 2023 Methodische onderbouwing van kengetallen gebruikt voor waardering van emissies en milieu-impacts Delft, CE Delft, februari 2023 Publicatienummer: 23.220175.034

Fischer, Paul H., Bert Brunekreef, Erik Lebret, Air pollution related deaths during the 2003 heat wave in the Netherlands, Atmospheric Environment, Volume 38, Issue 8, 2004, Pages 1083-1085, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2003.11.010.

Gezondheidsraad (GR) (2018): Gezondheidswinst door schonere lucht. Den Haag: Gezondheidsraad, 2018; publicatienr. 2018/01

Hall, E.F., R.J.M. Maas, J. Limaheluw, C.D. Betgen (2021). Mondiaal klimaatbeleid: gezondheidswinst in Nederland bij minder klimaatverandering. RIVM Rapport 2020-0200

Huynen, M., Vliet, A. van, Staatsen, B., Hall, L., Zwartkruis, J., Kruize, H., Betgen, C., Verboom, J. en Martens, P. (2019). Kennisagenda klimaat en gezondheid. ZonMw.

Jaakkola, Jouni J K, Simo-Pekka Kiihamäki, Simo Näyhä, Niilo R I Ryti, Timo T Hugg, Maritta S Jaakkola, Airborne pollen concentrations and daily mortality from respiratory and cardiovascular causes, European Journal of Public Health, Volume 31, Issue 4, August 2021, Pages 722–724, https://doi.org/10.1093/eurpub/ckab034

KNMI (2021). Klimaatsignaal '21. Hoe het klimaat in Nederland snel verandert, KNMI, De Bilt, 72 pp.

Maas, RJM, J Hoekstra, M Huitema, W de Vries, PG Ruyssenaars (2022). Inventarisatie van benodigde maatregelen om WHO-advieswaarden voor luchtkwaliteit in 2030 te realiseren, RIVM-rapport 2022-0094

MSC-W, (2021): Transboundary air pollution by sulphur, nitrogen, ozone and particulate matter in 2019 the Netherlands. Norwegian Meteorological Institute, Data Note 1/2021 ISSN 1890-0003. August 2021.

NIPV (2023). Natuurbrandsignaal ’23. Nederlands Instituut Publieke Veiligheid (NIPV).

Ruyssenaars, P.G., M.E. Gerlofs-Nijland, J. Hoekstra, M. Huitema, R.J.M. Maas, W. de Vries (2021). Monitoringsrapportage Doelbereik Schone Lucht Akkoord: eerste voortgangsmeting. RIVM-rapport 2021-0114

UNEP (2022a) United Nations Environment Programme. Spreading like Wildfire – The Rising Threat of Extraordinary Landscape Fires. A UNEP Rapid Response Assessment. Nairobi.

Van der Ree, J., C. Betgen, C. Boomsma, A. van Dijk, L. Hall, D. Houweling, J. Limaheluw, K. Rijs (2022) Plan van aanpak Onderzoeksprogramma Klimaatverandering en gezondheidseffecten. RIVM rapport 2022-0030

WHO (2021), WHO global air quality guidelines. Particulate matter (PM2,5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization; 2021. License: CC BY-NC-SA 3.0 IGO. Geneva.

5 Mental health fact sheet

RIVM expert: C. Boomsma, edited by: C.D. Betgen

The risk of negative mental health effects consists of the threat of acute, subacute or long-term consequences from extreme weather, rising temperatures and floods and overall increases in greenhouse gases in the atmosphere.

Introduction

Mental health is ‘a state of well-being in which an individual realises their own abilities, can cope with the normal stresses of life, can work productively and is able to make a contribution to their community.’ (WHO, 2022). It involves both the absence of mental disorders and broader mental well-being. The relationship between mental health and climate change has only recently been studied in greater depth. Research shows that climate change can have a variety of impacts on mental health (Sciberras and Fernando, 2022; Ma et al., 2022; Charlson et al., 2022; Palinkas & Wong, 2020; Lawrance et al., 2021; Berry et al., 2010). In the Dutch context, research on this topic is still limited (Van der Ree et al, 2022). WHO has identified the relationship between climate change and mental health as a priority for action because of the lack of attention to it in many countries.[38]

Climate threat

All climate threats are related to the possible occurrence of mental health risks. But the main ones are: rising temperatures, flood risks, extreme weather and the overall increase in greenhouse gases in the atmosphere.

When looking at the relationship between mental health and climate change, a distinction is often made between the effects of acute events or disasters related to extreme weather (floods, forest fires); subacute or long-term changes (droughts); and the overall threat of climate change (Palinkas & Wong, 2020).

Mental health effects can thus stem from a single traumatic event, but also from experiencing long-term changes year after year. For example, higher temperatures can lead to increased aggression in people, hospital admissions for mental symptoms and suicides (Thompson et al., 2018).

Mental health effects can be direct, as people are experiencing the effects of climate change first-hand. But the effects can also be indirect, as people are aware of, or are witnessing, the effects of climate change (without experiencing these effects first-hand) (Lawrance et al., 2021). The latter is sometimes referred to as 'climate anxiety' (also referred to as 'climate depression'), which means that a person is concerned about the current and future impacts of climate change, the uncertainty of the timing and location of these impacts and a lack of action to address

[38] https://www.who.int/news/item/03-06-2022-why-mental-health-is-a-priority-for-action-on-climate-change

climate change and its impacts (Clayton, 2020). In addition, actual or expected changes in the living environment due to climate change may lead to feelings of sadness, stress and grief (also called solastalgia or ecological grief; Lawrance et al., 2021; WHO, 2022; Hwong et al., 2022). Global research shows that many children and young adults are concerned about climate change (Hickman et al., 2021), but concerns are also prevalent among adults and the elderly. Recent Statistics Netherlands research (CBS, 2023) concluded that 76% of Dutch people aged 18 or older are concerned about the impacts of climate change on future generations. This research showed that older people were more concerned than younger people. These worries can have a knock-on effect on people's mental health.

Frequency
Climate change is causing increasingly extreme weather (KNMI, 2021). The frequency of extreme weather is expected to go up. This means that, for both acute (e.g. heatwaves) and subacute events (e.g. droughts), the frequency is increasing and therefore the frequency of mental health effects is also expected to increase. And with the increasing visibility of climate change impacts (IPCC, 2023), the number of people concerned about climate change (in the form of climate anxiety, for example) is also expected to increase (Heeren & Asmundson, 2023). For instance, in the 2023 Statistics Netherlands study, the proportion of Dutch people who are very concerned about climate change has increased slightly compared to 2020 (CBS, 2023). However, there is a lack of comprehensive data on the trend (so far, and looking ahead) of the mental health effects of climate change.

Secondary effects

Several secondary effects can be expected in climate-related mental health problems, such as work loss or social isolation.

Exposure

Exposure may be direct or indirect. Direct exposure involves experiencing extreme weather first-hand (for example, the residents of Valkenburg during the flooding of the river Geul in 2021). Indirect exposure is about observing extreme weather elsewhere (Dutch people reading about the flooding of the river Geul in the news). As far as direct exposure is concerned, spatial distinctions can be made within the Netherlands in terms of the likelihood of certain extreme weather events. Natural areas including dunes and forests are especially prone to wildfires, and villages and towns along rivers are vulnerable in terms of flooding from the river due to high runoff. But for many extreme weather events, it is impossible to predict where the likelihood of exposure is higher, as storms or downbursts resulting in damage can occur anywhere in the Netherlands. Subacute or long-term changes may be tied to regions more susceptible to drought and sea level rise. The overall threat of climate change is not directly tied to particular regions in the Netherlands.

Heat exposure is slightly more location-specific, though. Due to higher temperatures in cities (especially at night), these health effects could have a more urban component.

For indirect exposure (for example, via social or other media), it is not possible to distinguish certain regions in the Netherlands where exposure is more likely. This may also include indirect exposure to climate threats outside the Netherlands. However, it is expected that, if exposure is closer to home, the impact will also be greater.

Susceptibility

WHO (2022) identifies five factors that make individuals vulnerable to the mental health impacts of climate change: health factors (chronic health problems, physical disabilities, pre-existing mental health conditions); socio-economic factors (poverty, precarious housing and working conditions); demographic factors (age, gender, ethnicity); geographical factors (areas vulnerable to extreme weather); and socio-political factors (gender, discriminated groups).

Attitudes about climate change may also contribute to susceptibility. It is likely that people who do not recognise climate change (and/or think that climate change impacts are small) are less susceptible to some mental health effects (particularly related to the overall threat of climate change). Research shows that when people recognise that the climate is changing due to human influence and they think this will have negative consequences, they are more concerned about climate change. Across the political spectrum, there are concerns when humans are recognised as the cause of climate change and thus the cause of the negative impacts. However, this relationship is less strong for people on the right of the political spectrum (Gregersen et al., 2020). It is not yet known whether acute and subacute climate threats (such as extreme weather or rising temperatures) have a greater effect on mental health if people attribute these events to climate change.

Adaptive capacity

The many indirect and latent effects and contextual factors complicate research into the relationship between climate change and mental health and the steps that can be taken to reduce the impact of climate change on mental health (Van der Ree et al., 2022). Research on resilience (of individuals and groups) in the context of the mental health impacts of climate change is starting to pick up. A few examples can be found below:

- When people gain confidence that they themselves can play a role in preparing for and mitigating climate change, they also become more resilient to the psychological effects of climate change. Communicating specific solutions and highlighting co-benefits (such as about one's own health gains from cycling more or eating less meat) can help (Clayton et al., 2014).
- Young people experience more stress if they feel the government is not doing enough to combat climate change. It is expected that climate stress among young people could decrease if the government listens to young people's concerns, takes these concerns seriously, actively works to combat climate change and also communicates this to the outside world (Hickman et al., 2021).
- More examples can be found in: Doherty, 2018; Lawrance et al., 2021; Longman et al., 2023.

Outside the context of climate change, much research has been done on effective interventions and policies for mental health in society.[39]

Impact

The effects on mental health and emotional well-being can manifest as, for example, increased anxiety and stress, depression and anxiety disorders, post-traumatic stress disorder, sleep problems, increases in aggressive behaviour, feelings of fear and tension regarding the future and suicide (Palinkas & Wong, 2020).

Nevertheless, compared to physical health, there has been little attention to date for the impact of climate change on mental health in society, research and policy (Palinkas & Wong, 2020; Lawrance et al., 2021; Berry et al., 2010). There are occasional surveys that do ask one-off questions about climate concerns. Research has concluded that 65% of Dutch people are concerned about the climate (TNO, 2022). These concerns affect people's mental health and emotional well-being. A vast majority of young people (70%) are concerned about climate change. And one in five young people also say they experience regular to frequent stress when thinking about the climate crisis. The latter are mainly young people (16–24 years old) and young people who are highly educated (IPSOS, 2023).

This research was conducted among relatively small groups, but it does show high rates of concerns and stress. Recent Statistics Netherlands research (CBS, 2023) concluded that 76% of Dutch people aged 18 or older are concerned about the impacts of climate change on future generations, with older people being more concerned than younger people.

It seems like more people are experiencing extreme weather and/or are witnessing extreme weather in the media (like the summer of 2023, with forest fires, floods and storms), which can serve as stressors.

However, health care providers in the Netherlands do not yet record mental health problems related to climate change, so exact numbers on prevalence are lacking. Figures on the incidence of mental illness[40] are available. The percentage of adult Dutch people (18–64 years) with a mental illness in the past 12 months has increased sharply over the past 12 years: from 17% in 2007–2009 to over a quarter (26%) in 2019–2022.[41] The coronavirus pandemic does not seem to have affected these figures. RIVM has been monitoring the wider mental health[42] of young people and adults quarterly since September 2021, with the coronavirus pandemic being the original reason. Specifically among young people, there is still no improvement in mental health despite coronavirus measures having stopped.[43] Similarly, little improvement is seen in adults. The cause of this is unknown.

[39] https://www.rivm.nl/documenten/effectieve-interventies-en-beleid-mentale-gezondheid-en-preventie
[40] A person has a mental disorder if one or more of the following conditions is present: mood, anxiety, substance use disorders or ADHD.
[41] https://www.trimbos.nl/kennis/cijfers/psychische-gezondheid-ggz/
[42] The mental health monitor looks at mental well-being and mental problems in addition to mental disorders
[43] https://www.rivm.nl/nieuws/geen-verbetering-in-mentale-gezondheid-jongeren

Climate change has a significant impact on multiple facets of mental health. An increase in mental health care needs due to climate change is expected (Lawrance et al., 2021). Examples could include job losses, relationship break-ups and increased use of medicines. These are downward-spiralling consequences that affect the healthcare system and the economy.

Possible indicators (source):

- Acute events
  - psychological symptoms after a natural disaster (RIVM questionnaire);
  - health problems before and after severe weather and healthcare utilisation before and after severe weather (Netherlands Institute for Health Services Research, NIVEL).
- Subacute events
  - sentiment on social media during heatwaves (Lancet);
  - rise in temperatures/heat in relation to hospital admissions for mental health problems.

Overall threat of climate change
Indicators from various mental health monitors (Statistics Netherlands health survey, Statistics Netherlands health monitor, Municipal Public Health Services, RIVM).

Cascade effects

Almost all physical health threats linked to climate change are associated with negative mental health effects (Lawrance et al., 2021). This could, for example, spill over into the healthcare sector (more doctor visits, hospital admissions, medicines) and the economy (work loss).

It is possible that individuals or groups vulnerable to negative mental health effects of climate change are also vulnerable to other health effects of climate change. The opposite could also be true: a vulnerability to physical health effects could be a factor that also makes people vulnerable to mental health effects. It is therefore important to consider where and in which individuals vulnerabilities coincide and where a physical vulnerability might also create a mental vulnerability (Van der Ree et al., 2022).

An example of a cascade effect that can occur in relation to climate change is that a deterioration in air quality during a heatwave can lead to illness, which then leads to absenteeism at work, which in turn can cause stress, which can then lead to mental health problems (WHO, 2022). Also, high temperatures during a heatwave can cause concentration problems, which cause stress, which can cause people to become absent from work. In turn, this, too, can lead to acute negative effects on mental health.

Final impact: people

Recent years have seen an upward trend in mental health problems. In how far climate change has contributed to this has not yet been sufficiently researched. Climate change could create new mental health problems. It could also worsen existing symptoms. Mental health problems are a result of acute events, subacute/long-term events and the overall threat of climate change. From what is known about the number of people concerned about climate change and the links in terms of short and long-term categories and mental health, it is plausible that the mental health impact of climate change is high (>100,000 persons affected). People quickly fall under the category of 'affected', even in cases of anxiety or stress for which they will certainly not immediately see a doctor, and may therefore mostly remain unrecorded. On the other hand, anxiety or stress is also not an immediate cause of permanent or temporary mental health problems.

In particular, more research is needed, as it is also important to distinguish between short and long-term mental health effects. For example, anyone who experiences a disaster first-hand may experience symptoms at the moment of the disaster, in addition to long-term symptoms.

Final risk: economy

As mentioned earlier, an increase in mental health care needs due to climate change is expected (Lawrance et al., 2021). Examples could include work loss, relationship break-ups and increased use of medicines. These are downward-spiralling consequences that affect the healthcare system and the economy.

Better mental health leads to reduced healthcare costs and less absenteeism at work (RIVM, 2022a). If the mental health of one million adults improves by five per cent, it could save €144 million. Conversely, it stands to reason that if mental health deteriorates, this also causes higher costs. These figures are indicative and apply to the overall mental health status of Dutch people and are not specifically related to mental health problems due to climate change. More research into this is needed.

The estimated final impact on the economy is medium (€100 million–€1 billion).

Likelihood

The likelihood of acute climate threats such as extreme weather is once a year or more. Because extreme weather can often lead to locally severe situations (e.g. floods and downbursts), the likelihood of every Dutch person experiencing this once a year or more often is lower, and the current likelihood is once every 100 years to once every 10 years. The expectation that extreme weather will become more frequent due to climate change also leads to an increase in likelihood. For heatwaves and related mental health problems, the likelihood is from once every 10 years to once a year.

Subacute climate threats such as extended periods of drought have been frequent in recent years (2018, 2019, 2020, 2022). Rainfall deficits resulting in drought occur with a likelihood of once every 10 years to once a year. Subacute mental health problems will follow the same likelihood.

No likelihood can be attached to mental health effects due to the general threat of climate change. The threat is always there, but it will be fuelled in varying degrees of intensity on a daily basis by media coverage, for example.

Wildcards & tipping points

Extreme weather resulting in flooding and/or substantial damage or major social disruption is a wildcard that can happen. The extreme rainfall that caused the Geul valley in Limburg to flood in the summer of 2021 caused a lot of damage. Homes became uninhabitable, and many retail premises suffered extensive damage. A limited number of people were directly confronted with the fear of the flood and financial and other consequences, which undoubtedly also had an impact on mental health. South Limburg is a fairly sparsely populated area. Extreme weather in the Randstad conurbation would affect many more people and also causes more damage, followed by financial worries and anxiety, and therefore a higher impact on mental health.

Global instability (such as war and conflict and migration) and financial and other crises can additionally contribute to negative mental health.

Administrative situation

In the Netherlands, general practitioners are responsible for treating mild psychological symptoms. People with moderate to severe mental health complaints and problems are referred to basic mental healthcare or specialised mental healthcare.[44] The Dutch abbreviation for mental healthcare is GGZ (*geestelijke gezondheidszorg*). In 2022, a proposal (RIVM, 2022b) was made for mental health to become part of the National Prevention Agreement.[45] This was because of the shared urgency felt by national parties to do more for prevention in mental health. The pressure on the mental healthcare system is very high, partly due to pressure on overall care, an increase in perceived pressure at work and school, and the effects of the coronavirus pandemic. Besides the mental healthcare sector, several other parties are involved in the issue of mental health, such as RIVM, the Trimbos Institute and the Municipal Public Health Services.

When it comes to climate change and mental health, a group of psychologists recently set up the Climate Psychology Foundation,[46] which helps people with mental health problems related to the climate and trains psychologists to help people.

Coherence with other transitions and policies

Climate policies and the energy transition have links to mental health. It was mentioned earlier that if climate policies are not implemented fast enough, this can cause stress in young people. A government adopting effective and fast climate policies could have a positive effect on mental health.

[44] https://www.rijksoverheid.nl/onderwerpen/geestelijke-gezondheidszorg/basis-ggz-en-gespecialiseerde-ggz
[45] https://www.rijksoverheid.nl/onderwerpen/gezondheid-en-preventie/nationaal-preventieakkoord
[46] https://www.klimaatpsychologie.com/

The energy transition could result in concerns alongside positive health effects. Research is being launched at RIVM into the effects of energy transition measures in homes, including the effect on mental health. However, a change in the landscape, such as the installation of wind turbines, can also have a negative effect on mental health. Transportation of hazardous substances in the living environment as part of the energy transition that people are not familiar with may also increase concerns (e.g. ammonia and/or hydrogen).

The housing shortage, which might make the government switch to building in flood-prone areas, could also affect the mental health of people living there.

International aspects

No additional susceptibilities or dependencies from abroad can be directly identified. It is possible, however, that impacts (or perceived impacts) of climate change abroad (for example, floods or forest fires in other countries) may influence people's concerns about climate change in the Netherlands. Global climate policy developments may also contribute to the aforementioned climate anxiety. In addition, climate change may lead to an increase in international conflicts (WHO, 2022), for instance through an increase in international migration due to climate change. This could also contribute to climate anxiety.

Maladaptation and/or lock-ins

There is insufficient knowledge on this topic to make unequivocal statements about possible maladaptation and/or lock-ins. An example could be housing development in places that are not climate-proof. It is possible that people may experience mental health problems because they become/are aware that their house, for example, is in a potential flood zone.

Starting points for adaptation policy

Adaptation policies are already being taken up in many municipalities. Linking adaptation measures to improvements in mental health provides another argument for implementing adaptation measures where conviction is still needed. WHO (2022) advocates including climate change in programmes and policies on mental health. There are opportunities here to cooperate with disaster programmes and disaster preparation programmes. WHO also recommends that mental health be well integrated into programmes and policies on climate change and health.

Equity

As described under susceptibility, there are several factors that make individuals vulnerable to mental health problems due to climate change. There is often a combination of circumstances. People who already fall into a vulnerable group often also live in poorly insulated houses in the city. This makes them extra exposed to the effects of climate change, which can cause mental health problems more quickly.

It would be fair if adaptation measures (in public spaces and elsewhere) to reduce temperatures were initially applied in the neighbourhoods where the most vulnerable people live. Similarly, subsidies for climate-proofing homes should go to the people who cannot afford it now. This is also related to the Netherlands Scientific Council for Government Policy's (WRR; 2023) distribution of climate costs.

Transparency, aggregation and delineation

The data for determining the climate threat is based on quantitative data, measured and modelled by KNMI. The relationship between mental health and climate change is based on quantitative data from published research. Exposure data is largely based on quantitative data measured by KNMI and from published research. The information on susceptibility is based on quantitative data from published research and partly on a qualitative interpretation of that data. Information on adaptive capacity is mainly based on qualitative data (interviews and perceptions among people). The impact on mental health is often not directly related to climate change (see knowledge gaps). Research on this is mainly qualitative and involves a lot of interpretation of quantitative data.

The final impact on people is based on qualitative data from interviews. The estimate of the final risk to the economy is based on quantitative data on healthcare costs.

The likelihood is based on quantitative data measured by KNMI. The translation into mental health effects is an estimate based on that data.

Knowledge gaps

There are many knowledge gaps when it comes to mental health effects related to climate change. Many of these knowledge gaps are described in the report by Van der Ree et al. (2022). In addition, some of them have been discussed in this fact sheet. The many indirect and latent effects and contextual factors complicate research into the relationship between climate change and mental health and the steps that can be taken to reduce the impact of climate change on mental health (Van der Ree et al., 2022).

There is a lack of comprehensive data on the trend (so far, and looking ahead) of mental health effects of climate change. Care registrations in the Netherlands do not record mental health problems related to climate change, so exact numbers on prevalence are lacking. Mental health problems often have multiple determinants (climate change is not the only causal factor), which is why it is unlikely that this data will become available.
There is no knowledge of which specific climate threats in particular contribute to mental health risks. Moreover, it is not known whether acute and subacute climate threats (for example, extreme weather or rising temperatures) have a greater effect on mental health if people attribute these events to climate change.

Many figures are indicative and apply to the overall mental health status of Dutch people and are not specifically related to mental health problems due to climate change. More research into this is needed.

There is a lot of research measuring concerns about climate change, but there is still insufficient research into the relationship this has with further mental health effects. It is also important to consider where vulnerabilities overlap and where a physical vulnerability might also create a mental vulnerability (Van der Ree et al., 2022).

Uncertainty and reliability

During the expert session with PBL, it was concluded that mental health in relation to climate change is an emerging field that is currently increasingly being researched. In the Netherlands, limited research has been conducted into this. A link is likely, but a direct link is difficult to separate from other factors that affect mental health. For example, there are no figures on the basis of which a reliability category can be determined. However, the wording in the cited literature does assume a fairly high degree of certainty that the effects on mental health are going to have an impact.

Based on our research, we conclude that the reliability on the mental health effects of climate change is average. Uncertainty is likely.

Expert assessment

RIVM experts are involved in research proposals as well as reports and other publications on the topic and are aware of the latest literature and studies. Both internally and externally, they are involved in various working groups and national and international collaborations on the topic. Expert judgement has therefore been used extensively for this fact sheet.

As there is much integrality in health effects between the topics, the aim was to have all topic experts (or their substitutes) present during the expert sessions. PBL also regularly attended these sessions, including the expert session to determine uncertainty and reliability.

Mental health fact sheet references

Berry, H. L., Bowen, K., & Kjellstrom, T. (2010). Climate change and mental health: a causal pathways framework. International journal of public health, 55(2), 123-132

CBS (2023). Klimaatverandering en energietransitie. Opvattingen en gedrag van Nederlanders in 2023.

Charlson, F., Ali, S., Augustinavicius, J., Benmarhnia, T., Birch, S., Clayton, S., … & Massazza, A. (2022). Global priorities for climate change and mental health research. Environment international, 158, 106984.

Clayton, S., Manning, C. and Hodge, C. (2014). Beyond storms & droughts: the psychological impacts of climate change. Washington, D.C: American Psychological Association and ecoAmerica; 2014.

Clayton, S. (2020). Climate anxiety: Psychological responses to climate change. Journal of anxiety disorders, 74, 102263.
Doherty, T. J. (2018). Individual impacts and resilience. In Psychology and climate change (pp. 245-266). Academic Press.

Gregersen Thea, Doran Rouven, Böhm Gisela, Tvinnereim Endre, Poortinga Wouter (2020). Political Orientation Moderates the Relationship Between Climate Change Beliefs and Worry About Climate Change. Frontiers in Psychology, 11, 2020, doi 10.3389/fpsyg.2020.01573.

Heeren, A., & Asmundson, G. J. (2022). Understanding climate anxiety: What decision-makers, health care providers, and the mental health community need to know to promote adaptative coping. Journal of Anxiety Disorders, 102654.

Hickman, C., Marks, E., Pihkala, P., Clayton, S., Lewandowski, R., Mayall, E., Wray, B., Mellor, C., Susteren, L van (2021). Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. Lancet Planet Health 2021;5: e863-73

Hwong, A. R., Wang, M., Khan, H., Chagwedera, D. N., Grzenda, A., Doty, B., … & Compton, W. M. (2022). Climate change and mental health research methods, gaps, and priorities: a scoping review. The Lancet Planetary Health, 6(3), e281-e291.

IPSOS (2023). Grotere klimaatzorgen voor de generatie van morgen. Rapport voor Milieudefensie Jong. Project: 22087361.

IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647

KNMI (2021). Klimaatsignaal ’21. Hoe het klimaat in Nederland snel verandert, KNMI, De Bilt, 72 pp.

Lawrance, D. E., Thompson, R., Fontana, G., Jennings, D. N. (2021). The impact of climate change on mental health and emotional wellbeing: current evidence and implications for policy and practice. Grantham Institute. Briefing paper No 36, May 2021

Longman, J., Braddon, M., Verlie, B., Schlosberg, D., Hampshire, L., Hawke, C., … & Saurman, E. (2023). Building resilience to the mental health impacts of climate change in rural Australia. The Journal of Climate Change and Health, 12, 100240.

Ma, T., Moore J., Cleary, A. (2022). Climate change impacts on the mental health and wellbeing of young people: A scoping review of risk and protective factors. Social Science & Medicine 301 (2022), 114888. https://doi.org/10.1016/j.socscimed.2022.114888

Palinkas, L. A., & Wong, M. (2020). Global climate change and mental health. Current opinion in psychology, 32, 12-16.
RIVM (2022a). Effectieve interventies en beleid mentale gezondheid en preventie. Een overzicht van kansen en mogelijkheden per levensfase & economische baten

RIVM (2022b). Landelijke en lokale ambities mentale gezondheid en preventie. Verdiepende consultaties voor het thema mentale gezondheid in Nationaal Preventieakkoord.

Sciberras E. & J.W. Fernando (2022). Climate change-related worry among Australian adolescents: an eight-year longitudinal study. Child and Adolescent Mental Health 27, No. 1, 2022, pp. 22–29.

Thompson, R., R. Hornigold, L. Page, T. Waite (2018). Associations between high ambient temperatures and heat waves with mental health outcomes: a systematic review, Public Health, Volume 161, 2018, Pages 171-191, ISSN 0033-3506, https://doi.org/10.1016/j.puhe.2018.06.008

TNO (2022). Burgers over klimaatbeleid. Melanie Klösters, Geerte Paradies, Luise Schlindwein en Anika Batenburg. TNO 2022 P10568.

Van der Ree, J., C. Betgen, C. Boomsma, A. van Dijk, L. Hall, D. Houweling, J. Limaheluw, K. Rijs (2022). Plan van aanpak Onderzoeksprogramma Klimaatverandering en gezondheidseffecten. RIVM-rapport 2022-0030

WHO (2022). Mental health and climate change: policy brief. World Health Organization. ISBN: 9789240045125

WRR (2023). Rechtvaardigheid in klimaatbeleid. Over de verdeling van klimaatkosten. Wetenschappelijke Raad voor het Regeringsbeleid, Den Haag, 2023.

6 UV radiation fact sheet

RIVM expert: A. van Dijk, edited by: C.D. Betgen

Health risk factors for skin cancer are an increase in exposure and higher availability of UV radiation caused by less cloud cover, more sunshine hours and likely a change in behaviour due to an increase in temperature, among other things.

Introduction

Ultraviolet (UV) radiation is non-visible radiation coming from the sun. The ozone layer around the earth tempers the sun's UV radiation, so only a portion reaches the earth's surface. UV radiation has both positive and negative health effects for humans. A positive effect is that UV radiation on the skin produces vitamin D, which is needed for healthy bones and muscles. On the other hand, UV radiation causes skin burns and skin ageing in the short term. In the long term, UV radiation is the dominant cause of skin cancer (Van der Ree et al., 2022). UV radiation also contributes to cataract formation in the eye (Van Dijk et al., 2019). The three most common types of skin cancer are: basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and melanoma.

Climate threat

The main climate threat to health effects from UV exposure is: rising temperatures.

In the Netherlands, the amount of radiation reaching the Earth's surface, also called the available UV radiation, has increased in recent decades (Figure 6.1). This is because cloud protection has decreased, air quality has improved and the ozone layer has become thinner. Due to ozone depletion, the annual amount of available UV radiation in the Netherlands is now about 10% higher than in the early 1980s.[47] Due to climate change, the number of days with temperatures of at least 25 °C is increasing and there is a trend of increasing sunshine hours (Figure 6.2). The trend in increasing sunshine hours (in the sunny half of the year) is partly due to decreased humidity due to warming land. The increase in available UV radiation and the increase in sunshine hours lead to more frequent and greater exposure.

[47] https://www.rivm.nl/uv-ozonlaag-en-klimaat/historische-trends

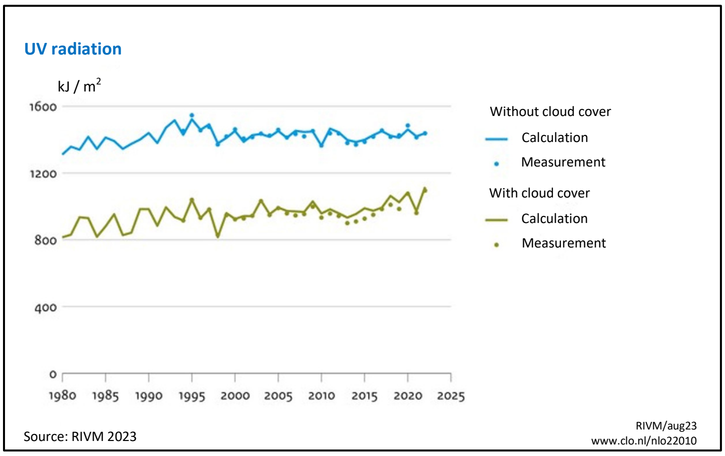


Figure 6.1 UV radiation annual sum in the Netherlands (source: RIVM, 2023)

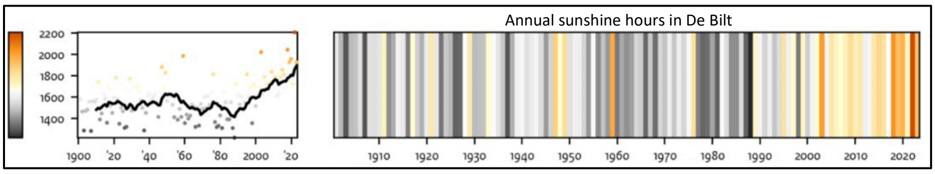


Figure 6.2 Annual sunshine hours in De Bilt (source: KNMI, 2023)

The UV index varies throughout the year. In autumn and winter, when the sun is lower on the horizon in the Netherlands, the UV index, like the number of hours of sunshine, is low. In spring and summer, the sun is higher on the horizon and the average UV index and sunshine hours are high (see Figure 6.3). Exposure also varies. In the colder months, when people are outside, only their hands, neck and face are exposed to the sun. In contrast, in spring and summer, almost the entire body is exposed to the sun when the weather is warm. Every skin is different, but from a UV index of 5, the skin can easily burn after about 25 minutes of exposure.

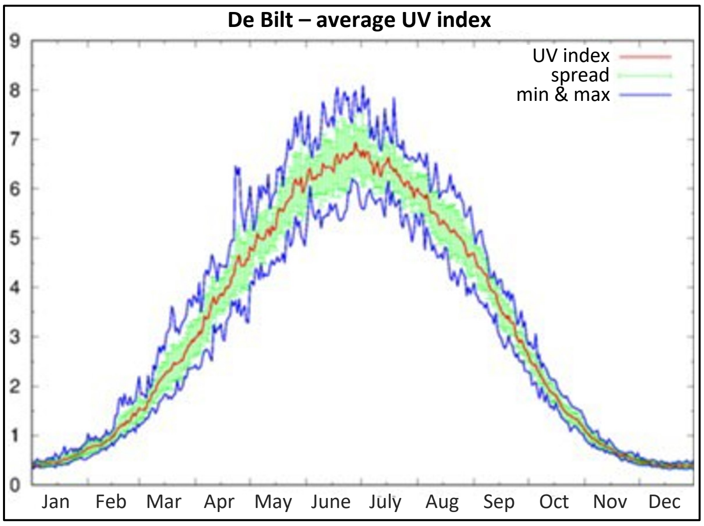


Figure 6.3 Average UV index over the year, measured in De Bilt (source: KNMI[48])

[48] https://www.knmi.nl/over-het-knmi/nieuws/meer-zon-iets-minder-zonkracht

Relevant indicators (source):

- UV index (measure of UV radiation) (RIVM) can be subdivided into:
  - erythemally weighted annual dose;
  - erythemally weighted monthly dose for each separate month;
  - ratio of measured actual erythema dose to the model for clear sky (as a measure of the dampening effect of clouds);
- the number of days on which a certain UV index was achieved (RIVM);
- the number of days with temperatures of at least 20 °C/25 °C/30 °C (KNMI);
- the number of sunshine hours (KNMI).

Secondary effects

Behaviour is a key aspect of health effects when it comes to UV exposure. Outdoor recreation is the most popular cluster of leisure activities, especially in spring (CBS, 2021). It is expected that more people will go outside in warmer and drier weather, and that they will expose a larger skin area than in colder weather. Both effects result in more UV exposure.

Since 1987, the Montreal Protocol[49] has been in force, setting rules to combat ozone depletion caused by chemical emissions. This protocol is bearing fruit and the ozone layer is recovering, although on the timescale of several decades. It will not return to pre-depletion levels, because climate change has changed the characteristics of the tropopauze, the layer between the troposphere and the stratosphere. UV exposure will not return to the same level either. In fact, the thickness of the ozone layer is not the only factor determining how much UV radiation is available and how much people expose their skin.

Exposure

Some groups of people have higher exposure than others. This may be related to a person’s profession; outdoor workers such as gardeners, construction workers, postmen and catering staff spend much more time outdoors than people with office jobs. Children and young people also spend more time outdoors. Outdoor athletes (and their audience) have relatively high exposure to UV radiation. And there are also those who deliberately go tanning to get a tan (outdoors or under a sunbed, for example).

The places where people live and/or take part in recreational activities may provide different UV exposures. For example, a day of recreation at the beach provides higher exposure than a day walking in the forest.

Under the influence of climate change, the amount of UV radiation reaching the ground will increase (this determines the UV index), but exposure will also change. Higher temperatures likely lead to more UV exposure because people will spend more time outdoors and also wear less skin-covering clothing at higher temperatures.

[49] https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol

In regions of the world where it is hot (above 30 degrees), higher temperatures lead to people spending less time outdoors, and therefore to less UV exposure. However, in cooler countries (with temperatures well below those 30 degrees, like the Netherlands), higher temperatures lead to people spending more time outdoors (EEAP, 2019). The number of warm days (>20 °C) and summer days (>25 °C) seems to be important for exposure. This is when people like to go outside and wear fewer clothes, which exposes more skin surface, and it is not yet so hot that they prefer to stay indoors (Schmalwieser et al., 2019).

Geography
The number of sunshine hours is not the same throughout the Netherlands, and there are therefore differences in UV exposure. In the west of the Netherlands, on the coast and in the Wadden region, the number of sunshine hours is higher than inland. In spring and summer, the coast can have an average of 100 more sunshine hours per month than in the eastern part of the country.[50] The Cancer Atlas[51] immediately shows that the average number of skin cancer diagnoses on the coast is higher than the Dutch average.

Susceptibility

Besides exposure, some groups of people are more susceptible to the health effects of UV radiation. People with fair skin burn faster and will need to protect their skin from sunlight more, and more often, than people with darker skin. Damage to the skin, such as scar tissue, also poses a risk of skin cancer. There are also people with a hereditary predisposition to skin cancer. In Germany, it has been shown that more than half of the medicines sold over the counter at pharmacies make people photosensitive. This means that the 'medicine, drug and alcohol users' group is also a risk group for UV radiation.

The number of new skin cancer diagnoses is now increasing sharply due to ageing. Older people have had chronic exposure to UV radiation in their lives. With an ageing population, this increase in skin cancer is expected to continue.

Besides ageing, registration figures in the Netherlands Cancer Registry (NCR), as provided by the Netherlands Comprehensive Cancer Organisation (IKNL), show another generational effect. The risk of skin cancer per person of a certain age increases with increasing year of birth. The actual cause of this trend, as mentioned earlier, is not yet known, and that is worrying.

Skin habituation plays a role in susceptibility. However, there is still a big knowledge gap here. According to the current social structure, large groups of Dutch people spend most of the year indoors: office workers, students. And in autumn and winter, there is very limited UV radiation in the Netherlands, as the sun is too low on the horizon then. As a result, the skin is no longer used to UV exposure and then becomes highly susceptible to UV radiation when exposed. During summer holidays, for example, Dutch people are suddenly exposed to large amounts of UV radiation, all over the

[50] https://www.knmi.nl/kennis-en-datacentrum/uitleg/zonnig
[51] https://kankeratlas.iknl.nl/

body, often in locations where the sun is higher on the horizon than in the Netherlands. If the skin is not used to this, this sudden transition is a possible recipe for melanoma (see impact).

Children are very susceptible to UV radiation for various reasons. Moreover, young children tend to spend a lot of time playing outdoors and being exposed to high levels of UV radiation. In addition, they are usually dependent on help from parents to take preventive measures.

The groups mentioned under the question on exposure are also vulnerable because they often seem unaware of the long-term and other dangers (medicine users, sunbed users) and/or cannot directly prevent exposure (outdoor workers or outdoor athletes).

Adaptive capacity

The potential adaptive capacity against UV exposure is high. This is because UV exposure is largely dependent on people's behaviour (Hall et al., 2021). Therefore, making an expectation for skin cancer due to additional UV exposure caused by climate change is also complex.

It is unknown how residents of the Netherlands will cope with rising temperatures due to climate change and whether associated behaviour will lead to reduced UV exposure. Relatively simple measures can already be taken to reduce exposure. When the UV index is high, one can reduce exposure by staying indoors, seeking shaded areas and protecting the skin by putting on protective clothes and applying sunscreen .

Current recommendations to protect yourself from UV radiation are based on 'Less is better'. However, it is also suspected that gradual habituation of the skin to UVB radiation may lead to thicker and darker skin. That thicker and darker skin can then, when the sun is higher on the horizon, provide significant protection from that more powerful sun. This natural adaptation option is not considered now. The possibilities of skin habituation need to be explored in good time so that they can be included in adaptation to the changing climate.

Only limited information is available on the behaviour (and awareness) of Dutch people regarding sunlight, and limited research has been conducted into the effects of interventions (Thoonen et al., 2022). The Dutch Ministry of Health, Welfare and Sport has asked RIVM to plan an information campaign on skin cancer (Thoonen et al., 2022). Recommendations from this plan focus on:

- increasing knowledge and awareness;
- changing various behaviours: (1) avoiding the sun, (2) covering your skin and only then (3) putting on sunscreen, instead of the other way around;
- addressing more specific behavioural determinants (for example, self-efficacy and creating action plans).

Because of children's susceptibility and lack of adaptive capacity, the proposed information campaign (Thoonen et al., 2022) therefore focuses partly on the target group 'parents and their primary school-aged children'. This campaign started in 2024 and will run for three years.

By carrying out a baseline measurement of people's knowledge, behaviour and perceptions in relation to sunlight now, it is possible to explore what interventions are needed to protect people from the negative consequences of increasing UV exposure due to climate change.

The UV index is now more widely publicised in weather forecasts. In public spaces, there is still much that can be done to reduce UV exposure, for example by creating more shaded areas. Initiatives for free sunscreen vending machines in public spaces, on beaches and at outdoor swimming pools are now on the rise.

Impact

Skin cancer rates in the Netherlands have risen much faster in recent decades than might have been expected based on ageing populations and ozone depletion. Since 1990, the incidence has quadrupled (Van Dijk et al., 2019). The graphs in Figures 6.4–6.6 show trends in the incidence of the three most common types of skin cancer: basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and melanoma. Every year, 80,000 Dutch people are currently told they have one of the forms of skin cancer (Thoonen et al., 2022), and around 900 Dutch people die of skin cancer every year.[52] The Netherlands has one of the highest incidences of the most dangerous form of skin cancer, melanoma, in Europe.

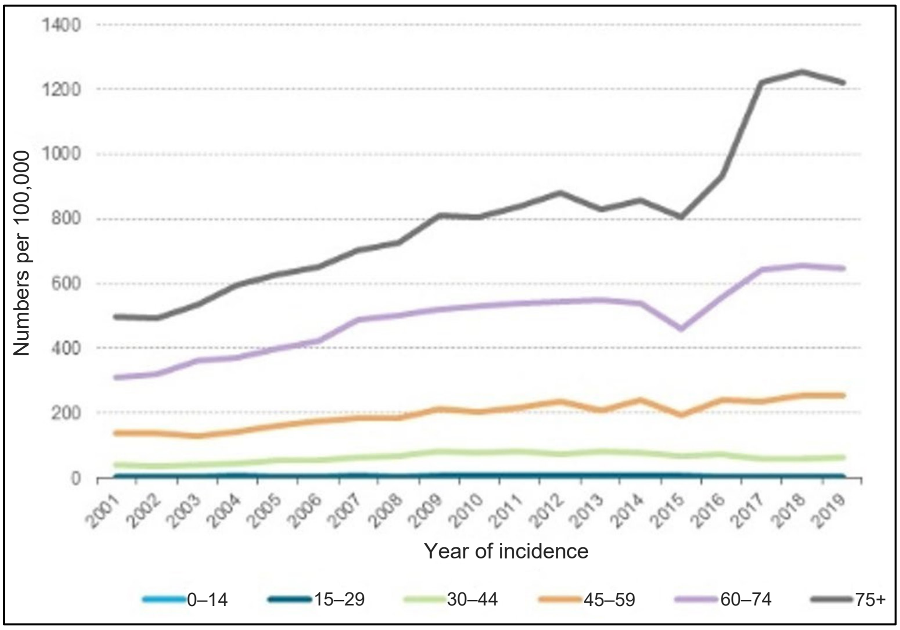


Figure 6.4 Incidence of basal cell carcinoma (BCC) by age from 2001 to 2020. Data and figures obtained from IKNL.

[52] https://iknl.nl/nkr-cijfers

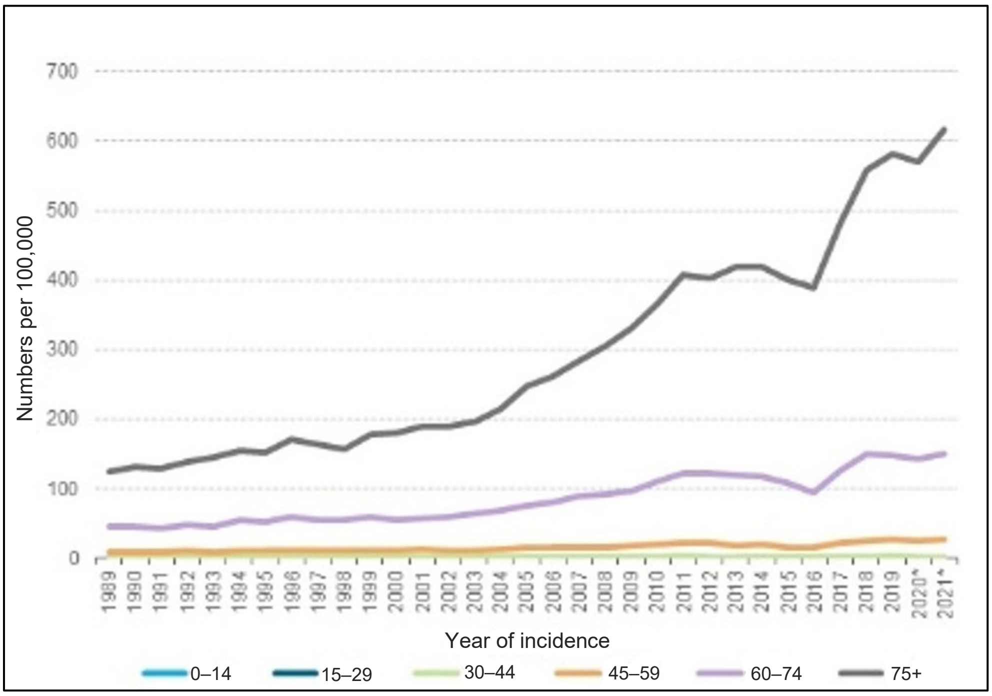


Figure 6.5 Incidence of squamous cell carcinoma (SCC) by age from 1989 to 2021. Data and figures obtained from IKNL.

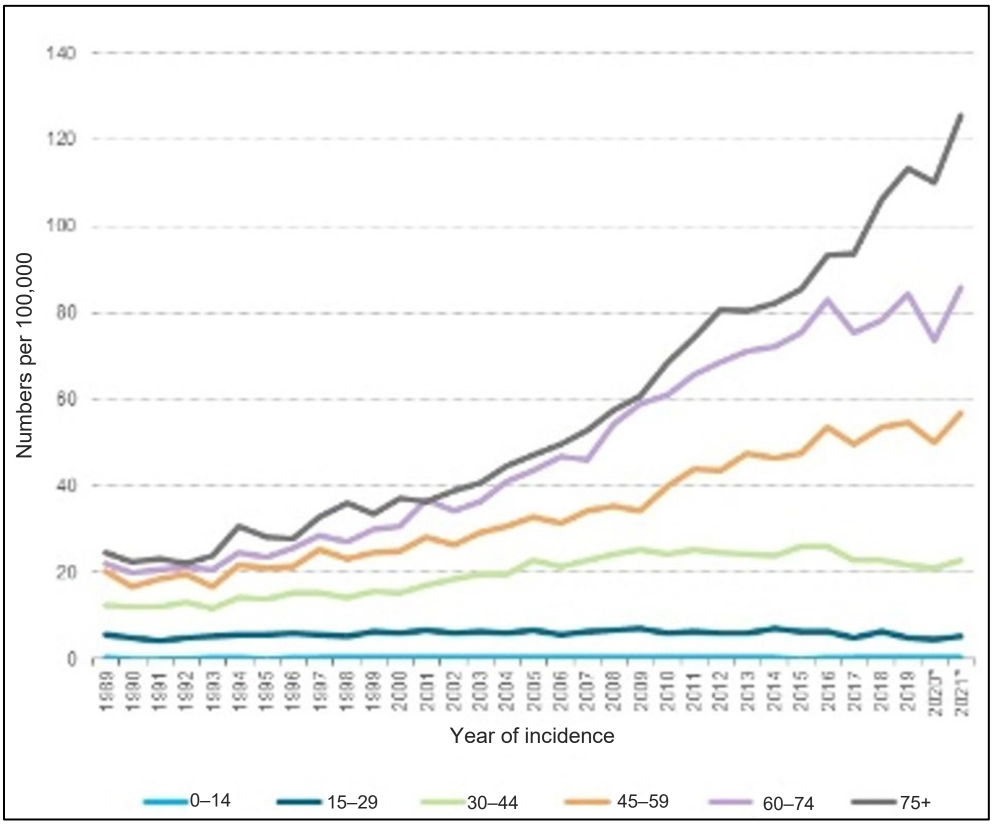


Figure 6.6 Incidence of melanoma by age from 1989 to 2021. Data and figures obtained from IKNL.

About half of the skin cancer cases can be attributed to ageing. The other half cannot yet be explained. Possible causes for the increase in skin cancer may lie in the increase in exposure (more recreation), change in cloud cover/air quality, increase in light sensitivity (for example, due to medication use) or less habituation, but changes in diagnostics may also contribute. For example, there are still many questions about UV radiation in relation to health and climate change that need to be addressed (Van der Ree et al., 2022).

Between UV exposure and the actual manifestation of skin cancer or cataracts, there is a big gap in time. Exposure in childhood, especially skin burns, can lead to skin cancer later in life. The large time interval makes it difficult to establish direct relationships. The duration and intensity of exposure affects the type of skin cancer associated with it. Squamous cell carcinoma appears to be caused by prolonged exposure to UVB radiation. UVB radiation occurs only in the middle of the day in spring and summer. Basal cell carcinoma is a form of skin cancer that develops from overexposure of young skin or intense recurrent exposure, including during puberty.[53] Basal cell carcinoma is easier to treat than squamous cell carcinoma. Melanoma is an aggressive form of skin cancer that can develop after short, intense exposure involving skin burns (Thoonen et al., 2022). UVA radiation is suspected to play a role in melanomas, in addition to UVB radiation. UVA radiation is present throughout the day and the year.

Relevant indicators (source):

- skin cancer incidence (IKNL);
- mortality from skin cancer (IKNL).

Cascade effects

A higher incidence of skin cancer entails more healthcare costs (treatment and medication). Hospitals need more specialists to treat the skin cancer.

The use of sunscreen as a form of protection against UV radiation can cause a negative impact on nature and the environment due to its ingredients. The use of sunscreen with certain ingredients such as oxybenzone and octinoxate is banned in countries like Hawaii and Thailand because they suspect that the substances affect coral.

Final impact: people

The incidence of skin cancer over the period 1991–2020 is largely a consequence of exposure that occurred earlier (possibly decades earlier) or during a longer preceding period. There can be as much as 40 years between initial or severe exposure and symptoms. Therefore, the increase in the available amount of UV radiation and the increase in exposure over the period 1991–2020 is not yet reflected in the 1991–2020 figures of skin cancer cases. The effects of exposure from 1991–2020 will only become visible in skin cancer cases over roughly the next 30 years. Since 1989, the number of skin cancer cases has quadrupled, half of which can be explained. The climate risk

[53] https://www.vzinfo.nl/huidkanker/oorzaken-en-gevolgen

depends on UV radiation, exposure and the occurrence of an effect. UV radiation is increasing, its effect increases over decades and the risk of skin cancer has been observed to increase with each successive generation. It is therefore plausible that climate change plays a role (as does behaviour).

Whether climate change explains the entire other half of the increase in skin cancer cases is not known. Because of the magnitude of the health effects, the sharp increase in the number of cases and the fact that the risk increases with each generation over the period 1991–2020, we estimate the climate risk as high (>10,000–100,000 persons affected and >100 deaths per year). A person affected is considered someone diagnosed with skin cancer.

Final risk: economy

Direct healthcare costs for skin cancer increased from €278 million in 2007 to €465 million in 2017 (Noels et al., 2020). These costs cover all types of skin cancer (there are more than mentioned in this fact sheet) and include hospital care and medication. The increase in healthcare costs is mainly due to the increase in skin cancer cases and medication costs. Skin cancer ranks fourth in terms of cost of cancer types.

As skin cancer rates are expected to increase, and the impact of climate change is not yet unambiguous, the final risk to the economy is estimated at medium (€100 million–€1 billion).

Likelihood

The risk of health effects from UV radiation is already present in the current situation. Depending on behaviour, the risk of skin cancer can be significantly reduced. Skin burns can occur when the UV index is high. This is the case throughout the sunny half of the year.

Wildcards & tipping points

Depletion of the ozone layer increases UV radiation on the Earth's surface. Agreements have been made to stop ozone depletion, and the ozone layer is recovering. However, developments can occur or substances can be released that will again deplete the ozone layer, increasing UV exposure.

Days on which the UV index is extremely high (especially in spring when people are not yet used to the sun) or a high UV index several days in a row could also be considered wildcards.

Administrative situation

As the number of skin cancer cases is increasing faster than expected, the urgency to tackle the problem has been increased by the Dutch Ministry of Health, Welfare and Sport. In 2019, the UV Index Action Plan (Thoonen et al., 2022) was set up, which resulted in the UV Index Action Platform. In this platform, RIVM works with 15 civil society partners to prevent skin cancer. The platform aims to reduce the incidence of skin cancer in the Netherlands and eye diseases caused by

UV radiation. By exchanging and pooling knowledge, affiliates ensure that their insights are up to date, and they speak with one voice.[54]

Coherence with other transitions and policies

There is a correlation between policies that focus on more exercise (outdoors). This includes specific initiatives aimed at getting children to play outside more. It is also linked to climate adaptation measures aimed at lowering temperatures. Measures to create shade, including through more trees, have a positive effect on reducing UV exposure. Mitigation measures generally have a positive effect on air quality, making the air cleaner and allowing more UV radiation to reach the surface.

International aspects

The ozone layer was severely depleted in the past by CFCs and HCFCs, among others. The Montreal Protocol (1987) was therefore enacted to protect the ozone layer. The protocol is a deal that all committed countries should adhere to. As long as this is adhered to, there are no susceptibilities from abroad when it comes to UV radiation in the Netherlands.

Maladaptation and/or lock-ins

There is a lot of misinformation regarding the use of sunscreen on social media in particular, where people advise against using sunscreen because sunscreen itself is said to be harmful to health and would cause vitamin D deficiencies. This type of incorrect information does not help raise awareness of the health risks of UV radiation and actually works against it.

In addition, research into skin habituation should therefore be conducted in good time, as it is suspected that it may play a role in protecting the skin from UV radiation.

Starting points for adaptation policy

The proposal for the information campaign as discussed earlier under adaptive capacity offers several starting points.

Furthermore, when designing public spaces, there are linkage opportunities to create shaded areas for cooling and reduced UV radiation exposure. Increasing the number of free sunscreen vending machines in places where exposure is high (beaches, swimming pools, terraces) is also a good initiative.

Equity

Professionals working outdoors cannot fully eliminate UV exposure, but measures can be taken that significantly reduce skin exposure. Clothing and covering the head can play a role in this. Adjusting working hours can be important here, thereby avoiding not only the hottest times of the day but also the time period with the highest UV index. These

[54] https://www.rivm.nl/zonkracht/samenwerkingsverbanden

measures should ideally be taken by employers to ensure that employees are properly informed and protected.
Schools can also take into account outdoor play times and adjust the daily schedule. Precisely because sunburn at a young age increases the risks of skin cancer later in life, it is important to properly protect this target group and raise awareness among teachers.

Good-quality sunscreen (without harmful substances for the environment) is often expensive. Initiatives which provide free sunscreen dispensers are therefore very important for people who cannot afford to buy sunscreen. In countries like Australia, it is quite common to be able to get sunscreen anywhere, and large packs (of several litres) are quite affordable there.

Transparency, aggregation and delineation

The data for determining the climate threat is based on quantitative data, measured and modelled by KNMI and RIVM. Information on exposure is mainly based on quantitative data. The information on susceptibility is based on quantitative data (for example, incidence of skin cancer by age group). The information on adaptive capacity is mainly qualitative data and estimates. Data on impact is based on quantitative data (incidence).

The final impact is based on quantitative data (burden of disease and mortality) and partly based on qualitative data (estimate of the share of climate change).

The likelihood is based on quantitative data.

Knowledge gaps

There are many knowledge gaps when it comes to UV radiation and health effects related to climate change. Many of these knowledge gaps are described in the report by Van der Ree et al. (2022).

Important knowledge gaps identified in this fact sheet focus mainly on how to explain the increase in skin cancer over the past decades and how to determine the share of climate change in the increase in skin cancer. Here, skin habituation and behaviour are important factors that require further research in order to better estimate the foreseeable health effects of UV radiation.

Uncertainty and reliability

When it comes to the relationship between UV radiation, exposure and skin cancer risk, reliability is very high and uncertainty is virtually certain. There is still little evidence of the relationship between the health effects of UV radiation and climate change, which is mainly due to the large time gap between exposure and getting skin cancer. Therefore, more research is needed in order to make any effective statements about this.

Expert assessment

RIVM experts are involved in research proposals as well as reports and other publications on the topic and are aware of the latest literature and studies. Both internally and externally, they are involved in various working groups and national and international collaborations on the topic. Expert judgement has therefore been used extensively for this fact sheet.

As there is much integrality in health effects between the topics, the aim was to have all topic experts (or their substitutes) present during the expert sessions. PBL also regularly attended these sessions, including the expert session to determine uncertainty and reliability.

UV radiation fact sheet references

CBS (2021). Trendrapport toerisme, recreatie en vrije tijd 2021. Samenstelling: NRIT, Centraal Bureau voor de Statistiek (CBS), Nederlands Bureau voor Toerisme & Congressen (NBTC) en Centre of Expertise Leisure, Tourism & Hospitality (CELTH). ISBN: 978-94-91625-15-2. Gebruikerslicentie: CBS.

EEAP (2019). Environmental Effects and Interactions of Stratospheric Ozone Depletion, UV Radiation, and Climate Change. 2018 Assessment Report. Nairobi: Environmental Effects Assessment Panel, United Nations Environment Programme (UNEP) 390 pp.

Hall, E.F., R.J.M. Maas, J. Limaheluw, C.D. Betgen (2021). Mondiaal klimaatbeleid: gezondheidswinst in Nederland bij minder klimaatverandering. RIVM-Rapport 2020-0200.

Noels, E., Hollestein L, Luijkx K, Louwman M, de Uyl-de Groot C, van den Bos R, van der Veldt A, Grünhagen D, Wakkee M. Increasing Costs of Skin Cancer due to Increasing Incidence and Introduction of Pharmaceuticals, 2007-2017. Acta Derm Venereol. 2020 May 28;100(10): adv00147. Doi: 10.2340/00015555-3463. PMID: 32189004; PMCID: PMC9137355.

Schmalwieser, A.W., Schmalwieser, V.T., Schmalwieser, S.S. (2019). Influence of Air Temperature on the UV Exposure of Different Body Sites Due to Clothing of Young Women During Daily Errands. Photochemistry and Photobiology, 2019, 95: 1068-1075. DOI: 10.1111/php.13088

Thoonen, K., A. van Dijk, W. Hagens (2022). Advies aan VWS over de inhoud van een voorlichtingscampagne over huidkanker. RIVM-rapport 2022-0063

Van der Ree, J., C. Betgen, C. Boomsma, A. van Dijk, L. Hall, D. Houweling, J. Limaheluw, K. Rijs (2022). Plan van aanpak Onderzoeksprogramma Klimaatverandering en gezondheidseffecten. RIVM-rapport 2022-0030

Van Dijk, A., W. Hagens, H. Slaper, M. Boekema (2019). Zonkrachtactieplan. RIVM-Briefrapport 2019-0078

7 Pollen allergies fact sheet

RIVM expert: E.F. Hall, edited by: C.D. Betgen

Health risk factors for pollen allergies (hay fever) are a longer pollen season, an increase in pollen concentrations and more allergenic pollen types caused by an increase in temperature and a rise in CO_2 in the atmosphere.

Introduction

Climate change negatively affects allergic conditions in several ways. Pollen allergies (hay fever) are the most common allergic conditions.

Hay fever is a seasonal condition caused by exposure to allergenic pollen from trees, grasses and weeds (such as annual ragweed). Most symptoms are caused by allergic rhinitis. Allergic rhinitis is an inflammation of the nasal mucosa due to hypersensitivity to allergens from plants, dust mites, fungi and/or pets. In addition, hay fever can cause allergic conjunctivitis, an inflammation of the eye mucosa.

Due to climate change, plants are subject to changes in temperature and humidity and will therefore change habitat and behaviour. This changes the exposure to the allergens produced by these plants.

Indoors, many people are allergic to allergens from house dust mites and mould, among others. Exposure to these allergens depends on, for example, indoor temperature and humidity. These factors are also affected by climate change (Hall et al., 2021). This fact sheet focuses on pollen allergies because the health effects are the greatest and there is a direct relationship with climate change.

Climate threat

The main climate threats affecting pollen allergies are: rising temperatures and rising CO_2 levels in the atmosphere. In the Netherlands, the annual mean temperature has increased by 2.3 °C since measurements began in 1901. The current CO_2 concentration in the atmosphere is about 420 ppm. This is already 100 ppm more than in 1960 when it was about 320 ppm.[55]

Climate change affects pollen season duration, pollen concentrations, species composition and allergenicity of pollen. The extent to which it does so is complex and species-dependent. Other factors are also important, such as changes in (extreme) weather, land use and air pollution.

The rise in temperature due to climate change is causing an earlier growing and flowering season in the Netherlands, and the growing season is getting longer. On average, the growing season starts three

[55] https://gml.noaa.gov/ccgg/trends/mlo.html

weeks earlier than 120 years ago,[56] and the growing season also lasts several weeks longer (see Figure 7.1).

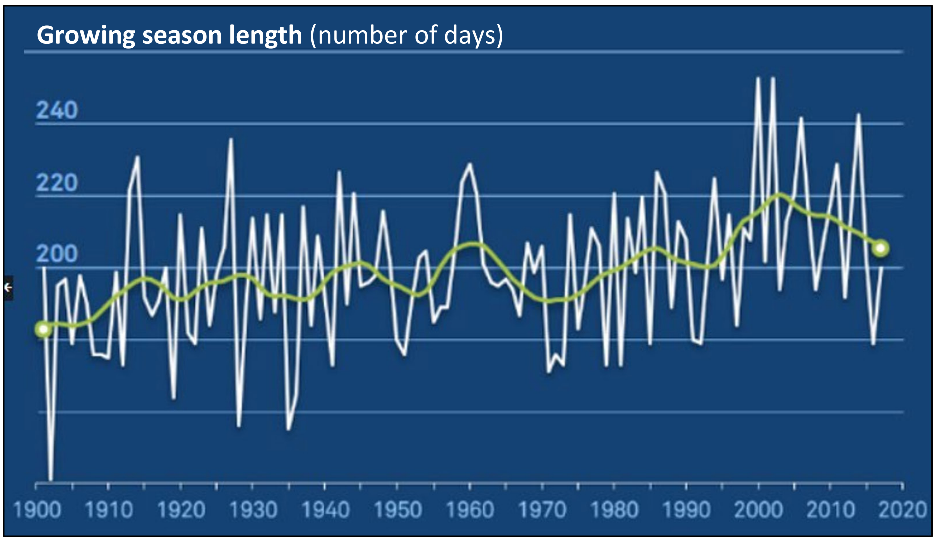


Figure 7.1 Length of growing season in the Netherlands (source: KNMI[57])

Rising temperatures and higher atmospheric CO_2 concentrations can lead to a longer pollen season and higher pollen production by plants and could potentially enhance pollen allergenicity (Zhang et al., 2022; Barnes, 2018; Weger & Hiemstra, 2009). A recent retrospective study of long-term trends in pollen concentrations in the northern hemisphere found an association between changes in maximum and minimum temperatures (associated with climate change) and increasing pollen concentrations and a longer pollen season (Ziska et al., 2019). A similar study in the Benelux countries found an increase in annual and peak pollen concentrations and a shift of the pollen season to earlier in the year for the tree species studied (Weger et al., 2021). Notably, a significant positive association between trends in pollen concentrations and trends in temperature was found for birch, the tree species with the most allergenic pollen in the Netherlands[58]. A longer pollen season and a decrease in pollen concentrations were found for grasses.
The researchers suspect that the decrease in grass pollen concentrations was caused by increased urbanisation near the two pollen monitoring stations (de Weger et al., 2021).

As average temperatures rise in the Netherlands, the habitat suitability for several heat-loving southern plant species is expanding northwards. As a result, the Netherlands is faced with non-native species that produce allergenic pollen, such as the olive tree and the annual ragweed plant. As annual ragweed flowers late in the season, after the native allergenic pollen has disappeared from the air, establishment of this species will prolong the allergenic pollen season (de Weger et al., 2009).

[56] https://www.knmi.nl/over-het-knmi/nieuws/groeiseizoen-kent-steeds-langer-nachtvorst
[57] https://www.knmi.nl/over-het-knmi/nieuws/hooikoorts-beinvloed-door-klimaatverandering
[58] https://www.lumc.nl/siteassets/over-het-lumc/maatschappelijke-rol/bomenkompas/bestanden/bomenkompas-brochure-5-apr-2023.pdf

Secondary effects

Extreme weather events often involve a combination of factors. For example, a heatwave may be accompanied by low precipitation and wind, resulting in poor air quality, with high concentrations of ozone (summer smog) and particulate matter in the air. Poor air quality, such as high ozone concentrations, creates a stress situation in plants that increases pollen allergenicity. This has been observed in annual ragweed and birch, for example. Drought can also create stress situations that increase pollen allergenicity (El Kelish et al., 2014). Heat may cause grasses to flower vigorously, resulting in a peak in grass pollen concentrations, such as in June 2023. This combination of conditions means that hay fever sufferers will experience more health problems (Huynen et al., 2019).

Besides morbidity, there is evidence that this combination of factors also contributes to excess mortality during a heatwave. Fischer et al. (2004) expected a substantial proportion of deaths now attributed to heat in the Netherlands to be caused by ozone and, to a lesser extent, particulate matter. Brunekreef et al. (2000) found a strong association between daily pollen concentrations and cardiovascular and respiratory mortality in the Netherlands. An association between pollen concentrations and mortality was also recently found in Finland (Jaakkola et al., 2021). However, Anenberg et al. (2020) concluded in a systematic review that there is limited evidence for synergistic effects of simultaneous exposure to (a) air pollution, pollen and heat; and (b) air pollution and pollen. With only one study, they could not assess the evidence for synergistic effects of heat and pollen. More research is needed into possible synergistic effects of heat, air pollution and pollen.

Exposure

Exposure to different types of pollen depends on the time of flowering of the trees, grasses and weeds, which depends on the climate (see above). Pollen is part of the reproductive cycle of plants and occur in the air when plants start flowering. Trees such as alder and hazel start flowering as early as February. For birch, the pollen peak is usually in April; by early June, the air is mostly free of tree pollen.[59] Grasses and weeds flower roughly from late April to September. The pollen calendar in Figure 7.2 shows when the various allergenic pollen types are found in the air in the Netherlands.

Exposure also depends on weather conditions. When it rains, exposure is lower because the pollen is washed out. In windy conditions, exposure may be greater as pollen is spread more widely.

[59] https://www.lumc.nl/patientenzorg/specialistische-centra/hart-long-centrum/voor-patienten/pollen-en-hooikoorts/

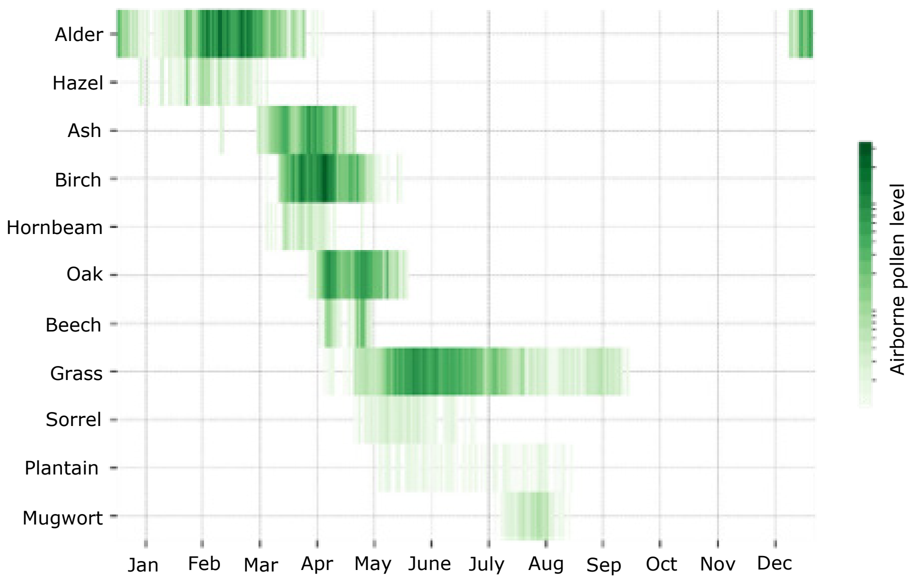


Figure 7.2 This pollen calendar is based on 10-year (2013-2023) pollen counts from the Leiden University Medical Centre. The darker the colour, the more pollen was observed at that time of year (source: LUMC[60]).

Rising temperatures caused by greenhouse gas emissions and higher atmospheric CO_2 concentrations may lead to a longer pollen season and higher pollen production by plants and could potentially enhance pollen allergenicity. As a result, the periods when different pollen types are found in the air become longer and symptoms can occur over a longer period of time and also be more severe.

Sapkota et al. (2019) studied whether there was an association between the incidence of hay fever among American adults and a change in the growing and flowering season in the USA associated with climate change and climate variability. They found an association between a higher prevalence of hay fever and both a very early onset of spring (> 3 weeks earlier than the long-term average) and a very late onset of spring (> 3 weeks later than the long-term average). An early onset of spring is associated with longer exposure to pollen. With a late onset of spring, more plants flower in a shorter period of time, resulting in a sharp peak in pollen concentrations (Sapkota et al., 2019).

In the Netherlands, the allergenic pollen that cause the majority of hay fever symptoms are those from birch and grasses, immediately followed by alder and hazel. In addition, pollen originating from ash, mugwort, sorrel and annual ragweed, for example, cause hay fever symptoms.[61] The species that cause hay fever symptoms are found throughout the Netherlands. Pollen also spreads through the wind, which can cause symptoms to manifest in places where the allergenic species is not directly present. Directly by the North Sea, on the beach, little pollen will be found with the prevailing south-westerly wind.

[60] https://www.lumc.nl/patientenzorg/specialistische-centra/hart-long-centrum/voor-patienten/pollen-en-hooikoorts/
[61] https://www.lumc.nl/patientenzorg/specialistische-centra/hart-long-centrum/voor-patienten/pollen-en-hooikoorts/

Annual ragweed has been found more frequently and in greater numbers in our country since the turn of the century, appearing in new areas. It is found regularly, especially in urban areas (Huynen et al., 2019). Floron (2023) studied the spread of ragweed from 1975 to 2022. This study shows that the number of observations of annual ragweed has increased sharply since 2005; see Figure 7.3.

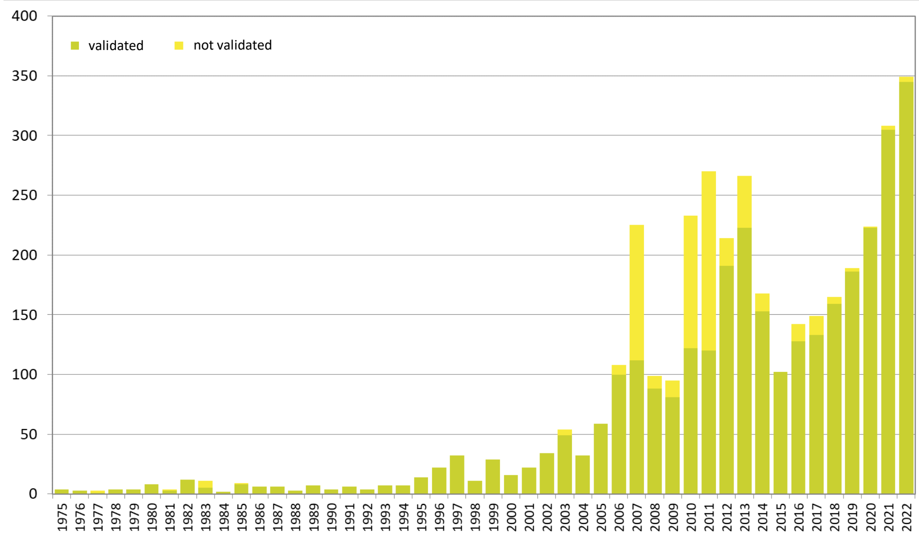


Figure 7.3 Number of kilometre blocks per year (y-axis) in which annual ragweed was observed from 1975 to 2022 (x-axis) (source: Floron, 2023).

People who participate in outdoor recreation or do a lot of outdoor sports are more likely to be exposed to pollen. People who work outdoors, such as construction workers, are also more exposed to pollen. If these people have hay fever, they will experience more symptoms due to their recreational and sports behaviour or working conditions.

Relevant indicators (source):
- pollen levels in the Netherlands, two monitoring stations (LUMC (Leiden), Elkerliek Hospital (Helmond));
- pollen dispersal in Europe (Polleninfo.org);
- modelling of pollen dispersal in Europe (SILAM; silam.fmi.fi/pollen.html).

Susceptibility

GP data shows that the number of new cases of allergic rhinitis (including hay fever) increases up to an age of between 19 and 24 years. After that, the number of new cases slowly decreases with age (NHG, 2018).

Climate change is expected to lengthen and intensify the pollen season, make pollen more allergenic and cause non-native allergenic species, such as annual ragweed, to become established in the Netherlands. It is therefore plausible that hay fever sufferers experience symptoms over a longer period of time and that these symptoms are also more severe. Also, more people may become sensitised to allergenic pollen, increasing the number of hay fever sufferers.

People with chronic respiratory diseases, such as asthma or a form of allergic rhinitis other than hay fever, are more susceptible to developing hay fever than those without respiratory diseases. They may be especially vulnerable when extreme situations occur. With poorer air quality, hay fever sufferers are also more susceptible to allergenic pollen (Huynen et al., 2019).

Adaptive capacity

Reducing exposure to pollen reduces hay fever symptoms. For this to occur, it is important that people know what pollen they are allergic to and what pollen is present in the air at any given time. Exposure to pollen is almost unavoidable, and weather conditions often determine the amount of pollen in the air. Measures that reduce symptoms somewhat include avoiding outdoor activities at times when concentrations of pollen (to which one is allergic) are high; drying laundry indoors so that pollen does not enter the home via the laundry; wearing glasses or sunglasses outdoors to avoid the eyes being exposed to pollen; and not mowing the grass during the flowering period.

Because it is difficult to avoid pollen, hay fever symptoms can be reduced by medication. In people with moderate to severe symptoms, the type of medication (corticosteroid nasal spray) works best when administered up to 10 days in advance. Similarly, the use of antihistamines for less severe reactions works best when administered several hours before exposure (Houweling et al., 2021). It is therefore important to know when high pollen concentrations of certain species are expected (Houweling et al., 2021).

In terms of managing their symptoms, hay fever sufferers would therefore greatly benefit from up-to-date pollen information for the whole of the Netherlands. There are currently only two monitoring sites (in Leiden and in Helmond) where pollen is counted manually and reported weekly (in retrospect) (see Administrative situation). With access to data on current pollen concentrations across the Netherlands, hay fever sufferers would be better able to manage their symptoms.

Measures based on adaptation policies could take into account avoiding the planting of highly allergenic species (see Starting points for adaptation policy).

Impact

Over 20% of Dutch people have mild to severe hay fever symptoms over a period of several years in their lives.[62] These symptoms occur when pollen to which one is allergic is present in the air. Hay fever sufferers may be allergic to one type of pollen but are often are allergic to several types of pollen, which can cause symptoms to persist for longer periods. Houweling et al. (2021) conducted a needs survey

[62] https://www.lumc.nl/patientenzorg/specialistische-centra/hart-long-centrum/voor-patienten/pollen-en-hooikoorts/

showing that 38% of respondents experience one to three months of symptoms per year and 45% experience more than three months.

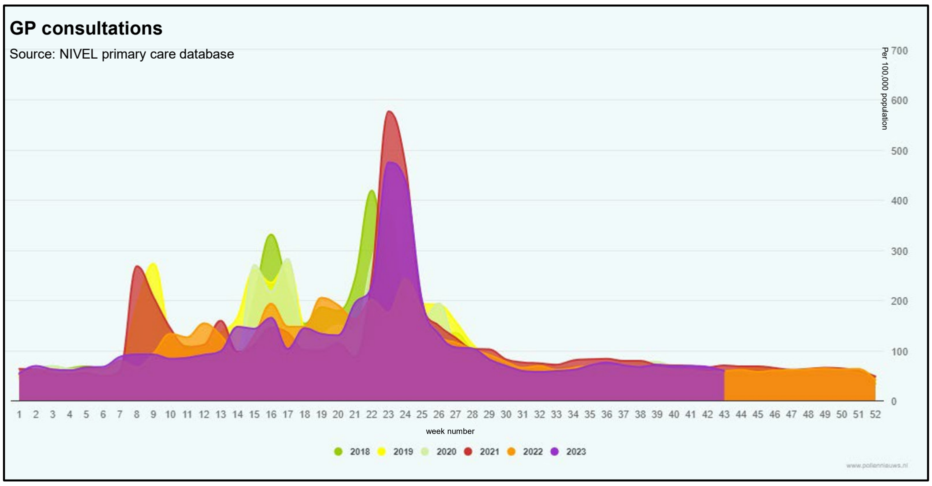


Figure 7.4 Registered number of people visiting GPs with hay fever symptoms. NIVEL collects data figures on this. The figure shows how many people per 100,000 residents presented to their GP with hay fever symptoms in the past six years. It shows that, in recent years, there have been peaks early in the season (early March) and that the highest peak in GP visits is in mid/late June (Source: NIVEL figures via pollennieuws.nl).

Hay fever patients often do not go to their GP with their symptoms, as a result of which the disease is under-diagnosed (Maurer et al., 2007) and the burden of disease in the Netherlands is not well known. People going to the GP are registered, and Figure 7.4 shows the number of GP consultations for hay fever symptoms between 2018 and 2023. In 2021, about 7.7% of the Dutch population used prescribed medication for allergic rhinitis (antihistamines and nasal sprays[63]). This is around 1.35 million people taking prescription medication for these symptoms. Because hay fever medication is freely available, there are also people with hay fever symptoms who do not go to the GP and instead buy their medication over the counter. In addition, some people do not know that their symptoms are caused by hay fever. The actual number of people who have hay fever and take medication can therefore not be stated with certainty

The main symptoms of hay fever are: an itchy or tickly nose and nasopharynx, sneezing, stuffy nose, watery eyes (bothered by bright light) and sometimes mild shortness of breath.[64] Besides these direct health effects, hay fever can lead to poorer sleep, difficulty concentrating and poorer functioning. This can lead to absenteeism, loss of labour productivity (Hellgren et al., 2010; Hoz Caballer, de la et al., 2013) and poorer school performance (Walker et al., 2007; Blaiss et al., 2018). Research on grass pollen allergy in some European countries (including the Netherlands) showed an average of almost four hours of sick leave per patient during the pollen season (Bachert et al., 2007).

[63] https://opendata.cbs.nl/#/CBS/nl/dataset/81071ned/table?searchKeywords=r06a
[64] https://www.lumc.nl/patientenzorg/specialistische-centra/hart-long-centrum/voor-patienten/pollen-en-hooikoorts/

The needs survey conducted by Houweling et al. (2021) showed that hay fever symptoms are perceived as moderately affecting daily life in 52% of cases, highly affecting daily life in 20% and very highly affecting daily life in 5%.

There is only one known study on the impact of increased temperatures due to climate change on GP consultations for hay fever. This study was conducted in the Netherlands in 3 GP practices over a 25-year period (Schreurs et al., 2022). For each year, a peak period was identified during which there was a significant increase in hay fever consultations. The duration of this peak period increased by an average of 1.3 days per year during the study period. There was also a statistically significant relationship between air temperature between February and July and the duration of the peak period.

The researchers compared the average start and duration of peak periods from 2015–2019 with the average start and duration of peak periods from 1995–1999. From 2015–2019, the average start of the peak period was four weeks earlier than from 1995–1999. Peak periods from 2015–2019 lasted on average 24 days longer than from 1995–1999 (122 days compared to 98 days). The researchers find it plausible that the earlier and longer hay fever season is caused by climate change (Schreurs et al., 2022). During this study, the average number of hay fever consultations per patient year increased from 2.0 during the first five years (1995–1999) to 2.2 during the last five years (2015–2019). This increase in consultations may indicate an exacerbation of hay fever symptoms and is considered clinically relevant (Schreurs et al., 2022).

The greatest impact on hay fever sufferers can be expected from the emergence of annual ragweed. Annual ragweed is the main source of hay fever and associated asthma in North America and has also spread through central Europe in recent decades.

Relevant indicators (source)

- the number of hay fever patients registered with GPs (Netherlands Institute for Health Services Research, NIVEL);
- the number of hay fever consultations per patient per year;
- the amount of hay fever medication sold (CBS; data from pharmacies).

Cascade effects

As mentioned earlier, hay fever often leads to impaired concentration and sleep problems, which can directly lead to absenteeism, loss of labour productivity and poorer school performance. This in turn can affect mental health, both directly and indirectly due to reduced income and financial problems.

Final impact: people

A hay fever sufferer can have mild symptoms, but some have severe symptoms that have a major impact on their daily functioning and can significantly reduce their quality of life (Muzalyova et al., 2019; Meltzer, 2001). The final-impact assessment assumes both mild and severe symptoms.

Many people have hay fever; in the Netherlands, this is estimated at 3.6 million people. The pollen season is starting earlier and getting longer. The findings of the aforementioned study (Schreurs et al., 2022) show the effects of this on hay fever, with an increase in GP consultations. Climate change contributes to this. Even though the extent to which climate change plays a role is not exactly clear, the number of people affected is high. The final impact on people when it comes to health problems due to an increase in hay fever caused by climate change is estimated to be high (>100,000 persons affected).

Final risk: economy

Besides physical symptoms, hay fever leads to absenteeism and reduced labour productivity, with these indirect costs proving to be higher than the direct costs of medical care. In a Spanish sample of patients at allergy clinics with hay fever, the average total cost was €1,485 per year, of which €1,036 were indirect costs related to absenteeism and reduced labour productivity (Colas et al., 2017). A Swedish study estimated the cost of absenteeism and reduced labour productivity at €961 per person per year (Cardell et al., 2016).

Based on these estimates, the cost of absenteeism and reduced labour productivity due to hay fever in the Netherlands is estimated to be around €1,000 per person per year. In 2023, 9.7 million people in the Netherlands were part of the active labour force.[65] If, according to estimates, 20% suffer from hay fever, with indirect costs of 1,000 euros per person per year, this represents an economic loss of almost 2 billion euros per year [(9,700,000 * 20/100) * 1,000 = 1.94 billion].

The extent to which climate change contributes to the number of hay fever patients has not yet been elucidated. The estimate is that the final risk to the economy is medium (€100 million–€1 billion) but that more research could show a high final risk (> €1 billion).

Likelihood

Hay fever is an annual issue. Hay fever peaks are expected to last longer with the first peak being earlier in the year and the last peak later in the year.

Research by Schreurs et al. (2022) shows that the hay fever season started four weeks earlier from 2015–2019 compared to 1995–1999. Also, peak periods from 2015–2019 lasted 24 days longer on average than from 2015–2019 (122 days compared to 98 days).

Wildcards & tipping points

A wildcard could be said to exist when the conditions for heat, drought and high pollen concentrations coincide in such a way that a hot period of prolonged poor air quality occurs (see secondary effects). It seems that this effect can already be seen in GP registration data (see impact), but no

[65] https://www.cbs.nl/nl-nl/visualisaties/dashboard-beroepsbevolking/werkzaam

research data is available yet. A larger number of people could become susceptible to respiratory symptoms under these conditions in the future.

Climate, nature and agricultural policies may cause changes in the species and number of allergenic plants in the Netherlands.

Thunderstorm asthma is a phenomenon that has been studied mainly in the UK and Australia (Thien et al., 2018) and it has also been described in some other countries (Italy, US, Canada, China). During warm weather, much allergenic grass pollen is formed. If this is followed by intense thunderstorms, it can be accompanied by more and severer asthma attacks because of the disintegration of the pollen into smaller particles that can be inhaled deep into the lungs. In the worst case described to date, in 2016, more than 3,000 patients with asthma attacks ended up in emergency departments in Melbourne, Australia, after a severe thunderstorm (Thien et al., 2018). It is as yet not clear whether thunderstorm asthma also occurs in the Netherlands (Huynen et al., 2019).

Possible indicator of thunderstorm asthma:
- combination of days with thunderstorms (KNMI) with:
- the number of patients with asthma attacks in emergency departments (VEKTIS).

Administrative situation

GPs are responsible for treating hay fever symptoms, and the Dutch College of General Practitioners has a guideline for treating allergic rhinitis (NHG, 2018). However, many patients treat the symptoms themselves with over-the-counter medication and do not visit their GP.

Municipal Public Health Services (GGDs) support municipalities and the public with questions and policies about a healthy living environment. Pollen allergies are taken into account when advising on green measures (for example, in the context of climate adaptation). A fact sheet has been prepared for GGD staff to support them in this.[66]

There are only two monitoring sites in the Netherlands where pollen is manually counted, at Leiden University Medical Centre and Elkerliek Hospital in Helmond. To better understand pollen concentrations so that the right measures can be taken at the right time, it is important that pollen concentrations are accurately measured and predicted (through modelling). Automation and expansion of this network would provide more and more up-to-date data and allow better monitoring for pollen. Therefore, a pollen monitoring network has been proposed (Houweling et al., 2021).

On a European scale, 31 European national meteorological services (EUMETNET) are collaborating in the AutoPollen Programme[67] to measure pollen. The Netherlands is not participating in this. Besides developing an automated pollen monitoring network for Europe, the project aims to make real-time pollen counts and forecasts available to the general public, doctors and health organisations.

[66] https://www.rivm.nl/media/240131
[67] https://autopollen.net/

There are no legal standards dictating which trees, herbaceous plants or grasses can be planted where.

Coherence with other transitions and policies

There is a direct link to green climate adaptation measures (see maladaptation).

International aspects

Pollen moves through the air, and that does not stop at the national border. Pollen can be transported by air for up to hundreds of kilometres. Even pollen originating from Ukraine has been found in the Netherlands (Huynen et al., 2019).

Maladaptation and/or lock-ins

Greening of the living environment to make it more climate adaptive and healthy may be accompanied by an increase in allergenic plants. It is therefore important to plant the right trees, herbaceous plants and grasses to avoid health problems.

From a biodiversity perspective, it is better let grasses and other plants grow longer and to mow less. However, this may actually lead to more pollen being produced.

Starting points for adaptation policy

Information on allergenic plants, such as the Bomenkompas guide on trees and pollen,[68] should be widely disseminated among organisations involved in greening the living environment. Managers of green spaces can then ensure that allergenic plants are avoided as much as possible in new plantings in public spaces. It is a quick win to make managers of green spaces, horticulturists and landscapers aware of the negative health effects of certain trees, herbaceous plants and grasses.

The GGD's fact sheet[69] also helps in this regard. The fact sheet describes what to take into account when landscaping green spaces to ensure that they don’t lead to people developing more allergic symptoms. Based on a systematic literature review, the following advice is given:

- General advice: Involve a botanist.
- Choose plants with low allergenicity and from various species groups.
- Choose plants that are not wind pollinated and with a short pollen period.
- Choose more female plants of dioecious species.
- Ensure adequate airflow.
- Avoid invasive species and other exotic plants.
- Provide variety in planting (increase biodiversity).
- Proximity of water can help.
- Maintain the green space.

[68] https://www.lumc.nl/siteassets/over-het-lumc/maatschappelijke-rol/bomenkompas/bestanden/bomenkompas-brochure-5-apr-2023.pdf
[69] https://www.rivm.nl/media/240131

Equity

People who work outdoors, such as construction workers, are more exposed to pollen. If these people have hay fever, they will experience more symptoms due to their working conditions. These people would particularly benefit from timely hay fever forecasts to allow them to take preventive medication. They cannot avoid hay fever because of their work.

Transparency, aggregation and delineation

The data for determining the climate threat is based on quantitative data, measured by KNMI. The data on pollen concentrations is based on quantitative data from various pollen surveys. Exposure data is based on quantitative data retrieved by pollen measurements and quantitative measurements of the length of growing seasons. Information on susceptibility is based on quantitative data from GPs. Information on adaptive capacity is mainly based on quantitative data (medicine effects/measures to reduce pollen/reproductive cycle of plants).

The impact or final impact is based on quantitative information on GP consultations and direct and indirect health costs.

The likelihood of occurrence of the impacts is based on previous quantitative weather data from KNMI, pollen data and GP consultations.

Knowledge gaps

There are many knowledge gaps when it comes to the health effects of hay fever in relation to climate change. Many of these knowledge gaps are described in the report by Van der Ree et al. (2022).

An important knowledge gap is the lack of research on the contribution of heat, air pollution and pollen to mortality and the burden of disease in warm periods, especially because climate change is expected to exacerbate these exposures.

Uncertainty and reliability

Most research is done on the duration and intensity of the pollen season. This research shows that the pollen season is starting earlier and getting longer and that pollen production is increasing. This has been observed worldwide, and there is consensus that this trend is continuing. Reliability in this respect is very high, and certainty is ranked as virtually certain.

Little research has been done on the health impacts of these trends in pollen exposure, and the current burden of disease and societal costs due to hay fever in the Netherlands are not known. Many patients treat their symptoms themselves, so the data from GP records is considered an underestimate. The extent to which trends in duration and intensity of the pollen season affect the burden of disease and societal costs cannot therefore be quantified with certainty. It is very likely, however, that the burden of disease and societal costs will increase. However, reliability is still low.

Expert assessment

RIVM experts are involved in research proposals as well as reports and other publications on the topic and are aware of the latest literature and studies. Both internally and externally, they are involved in various working groups and national and international collaborations on the topic. Expert judgement has therefore been used extensively for this fact sheet.

As there is much integrality in health effects between the topics, the aim was to have all topic experts (or their substitutes) present during the expert sessions. PBL also regularly attended these sessions, including the expert session to determine uncertainty and reliability.

Pollen allergies fact sheet references

Anenberg, S.C., Haines, S., Wang, E. *et al.* (2020). Synergistic health effects of air pollution, temperature, and pollen exposure: a systematic review of epidemiological evidence. Environ Health 19, 130 (2020). https://doi.org/10.1186/s12940-020-00681-z.

Bachert, C., Vestenbaek, U., Christensen, J., Griffiths, U.K., Poulsen, P.B. (2007). Cost effectiveness of grass allergen tablet (GRAZAX) for the prevention of seasonal grass pollen induced rhinoconjunctivitis – a Northern European perspective. Clin Exp Allergy 2007;37(5):772-9. DOI: 10.1111/j.1365-2222.2007.02706.x.

Barnes, C.S. (2018). Impact of Climate Change on Pollen and Respiratory Disease. Current Allergy and Asthma Reports 18(11): 59. DOI: 10.1007/s11882-018-0813-7.

Blaiss, M.S., Hammerby, E., Robinson, S., Kennedy-Martin, T., Buchs, S. (2018). The burden of allergic rhinitis and allergic rhinoconjunctivitis on adolescents: A literature review. Ann Allergy Asthma Immunol 121 (2018) 43–52 DOI: 10.1016/j.anai.2018.03.028

Brunekreef, Bert, Gerard Hoek, Paul Fischer, Frits Th M Spieksma (2000). Relation between airborne pollen concentrations and daily cardiovascular and respiratory-disease mortality. The Lancet Research letters. Vol 355. April 29, 2000

Cardell, LO., Olsson, P., Andersson, M. et al. (2016). TOTALL: high cost of allergic rhinitis—a national Swedish population-based questionnaire study. Npj Prim Care Resp Med 26, 15082 (2016). https://doi.org/10.1038/npjpcrm.2015.82

Colás, C., M. Brosa, E. Antón, J. Montoro, A. Navarro, M. T. Dordal, I. Dávila, B. Fernández-Parra, M. D. P. Ibáñez, M. Lluch-Bernal, V. Matheu, C. Rondón, M. C. Sánchez, A. Valero (2017). Estimate of the total costs of allergic rhinitis in specialized care based on real-world data: the FERIN Study. Allergy, 72:6, 959:966

El Kelish, A, Zhao F, Heller W, *et al.*. (2014). Ragweed (*Ambrosia artemisiifolia*) pollen allergenicity: superSAGE transcriptomic analysis upon elevated CO_2 and drought stress. BMC Plant Biol. 2014;14:176. https://doi.org/10.1186/1471-2229-14-176.

Fischer, Paul H., Bert Brunekreef, Erik Lebret (2004). Air pollution related deaths during the 2003 heat wave in the Netherlands, Atmospheric Environment, Volume 38, Issue 8, 2004, Pages 1083-1085, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2003.11.010.

Floron (2023). Analyse trend en hotspots Alsemambrosia.

Hall, E.F., R.J.M. Maas, J. Limaheluw, C.D. Betgen (2021). Mondiaal klimaatbeleid: gezondheidswinst in Nederland bij minder klimaatverandering. RIVM-Rapport 2020-0200.

Hellgren, J., Cervin, A., Nordling, S., Bergman, A. and Cardell, L.O. (2010). Allergic rhinitis and the common cold – high cost to society. Allergy 2010; 65: 776-783. DOI: 10.1111/j.1398-9995.2009.02269.x

Houweling, D., J. van der Helm, A. Versteeg-de Jong, J. Wesseling, C. Boomsma, S. van Wijk (2021). Advies over nut en noodzaak van een pollenmeetnetwerk. RIVM-briefrapport 2021-0221.

Hoz Caballer, B. de la, Rodriguez ,M., Fraj, J., Cerecedo, I., Antolin-Amerigo, D. and Colas, C. (2013). Allergic rhinitis and its impact on work productivity in primary care practice and a comparison with other common diseases: the Cross-sectional study to evAluate work Productivity in allergic Rhinitis compared with other common dIseases (CAPRI) study. Am J Rhinol Allergy 2013;26:390-394. DOI: 10.2500/ajra.2012.26.3799

Huynen, M., Vliet, A. van, Staatsen, B., Hall, L., Zwartkruis, J., Kruize, H., Betgen, C., Verboom, J. en Martens, P. (2019). Kennisagenda klimaat en gezondheid. ZonMw.

Jaakkola, Jouni J K, Simo-Pekka Kiihamäki, Simo Näyhä, Niilo R I Ryti, Timo T Hugg, Maritta S Jaakkola (2021). Airborne pollen concentrations and daily mortality from respiratory and cardiovascular causes, European Journal of Public Health, Volume 31, Issue 4, August 2021, Pages 722–724, https://doi.org/10.1093/eurpub/ckab034.

Maurer, M. & Zuberbier, T. (2007). Undertreatment of rhinitis symptoms in Europe: findings from a cross-sectional questionnaire survey. Allergy. 2007;62(9):1057-63.

Meltzer, Eli O. (2001). Quality of life in adults and children with allergic rhinitis, Journal of Allergy and Clinical Immunology, Volume 108, Issue 1, Supplement, 2001, Pages S45-S53, ISSN 0091-6749, https://doi.org/10.1067/mai.2001.115566.

Muzalyova, A., Brunner, J.O., Traidl-Hoffmann, C. et al. (2019). Pollen allergy and health behavior: patients trivializing their disease. Aerobiologia 35, 327–341 (2019). https://doi.org/10.1007/s10453-019-09563-5.

NHG (2018). NHG-Standaard. Allergische en niet-allergische rinitis (M48). Versie 3.0, januari 2018. Nederlands Huisartsen Genootschap.

Schreurs, W., Schermer, T.R.J., Akkermans, R.P. et al. (2022). 25-year retrospective longitudinal study on seasonal allergic rhinitis associations with air temperature in general practice. Npj Prim. Care Respir. Med. 32, 54 (2022). https://doi.org/10.1038/s41533-022-00319-2.

Sapkota, A., Murtugudde, R., Curriero, F.C., Upperman, C.R., Ziska, L., Jiang, C. (2019). Associations between alteration in plant phenology and hay fever prevalence among US adults: Implication for changing climate. PloS ONE 14(3): e0212010. https://doi.org/10.1371/journal.pone.0212010.

Thien, F., Beggs, P.J., Csutoros, D., Darvall, J., Hew, M. et al. (2018). The Melbourne epidemic thunderstorm asthma event 2016: an investigation of environmental triggers, effect on health services, and patient risk factors. Lancet Planet Health 2018; 2: e255–63.

Van der Ree, J., C. Betgen, C. Boomsma, A. van Dijk, L. Hall, D. Houweling , J. Limaheluw, K. Rijs (2022) Plan van aanpak Onderzoeksprogramma Klimaatverandering en gezondheidseffecten. RIVM-rapport 2022-0030.

Walker, S., Khan-Wasti, S., Fletcher, M., Cullinan, P., Harris, J., Sheikh, A. (2007). Seasonal allergic rhinitis is associated with a detrimental effect on examination performance in United Kingdom teenagers: casecontrol study. J Allergy Clin Immunol 2007; 120(2):381-7 DOI:10.1016/j.jaci.2007.03.034.

Weger, L.A. de, Bruffaerts, N., Koenders, M.M.J.F., Verstraeten, W.W., Delcloo, A.W., Hentges, P. and Hentges, F. (2021). Long-Term PollenMonitoring in the Benelux: Evaluation of Allergenic Pollen Levels and Temporal Variations of Pollen Seasons. Front. Allergy 2:676176. Doi:10.3389/falgy.2021.676176.

Weger, Letty A. de, Abraham C. van der Linden, Ingrid Terreehorst, Wout J. van der Slikke, Arnold J.H. van Vliet, Pieter S. Hiemstra (2009). Ambrosia in Nederland; Allergische sensibilisatie en verspreiding van planten en pollen. Ned Tijdschr Geneeskd. 2009;153:B340.

Weger, L.A. de en Hiemstra, P. (2009). Klimaatverandering en pollenallergie in Nederland. Ned Tijdschr Geneeskd. 2009;153:A1410.

Zhang, Y., Steiner, A.L. (2022). Projected climate-driven changes in pollen emission season length and magnitude over the continental United States. Nat Commun 13, 1234 (2022). https://doi.org/10.1038/s41467-022-28764-0.

Ziska, L.H., Makra, L., Harry, S.K. (2019). Temperature-related changes in airborne allergenic pollen abundance and seasonality across the northern hemisphere: a retrospective data analysis. Lancet Planet Health 2019; 3: e124-31. https://doi.org/10.1016/S2542-5196(19)30015-4.

8 Infectious diseases fact sheet

RIVM expert: J. Limaheluw, edited by: C.D. Betgen

The health risk for infectious diseases is affected by rising temperatures, changes in precipitation, evaporation and UV radiation, and an increase in flood probability and vectors. This leads to a more favourable environment for certain new and existing infectious diseases.
The pathogens that cause these infectious diseases can be transmitted through water, air, soil or food and by vectors.

Introduction

Many pathogens (bacteria, viruses, parasites, fungi, amoebas, worms) are climate sensitive. Pathogens can be transmitted through the environment (water, air, soil), food (for example, *Campylobacter* and *Vibrio*) and through vectors (mosquitoes and ticks). The occurrence of pathogens and human transmission and exposure are influenced by climatic factors such as temperature and humidity. Besides climate change, other factors such as internationalisation (transport and travel), forced and voluntary migration, urbanisation and ageing, climate adaptation measures and other current and future developments in the living environment also influence the infectious disease burden.

To better understand the impact of climate change on infectious diseases, RIVM is taking stock of existing knowledge, generating new knowledge and developing and redeveloping models to quantify the effect of climate change. This fact sheet discusses vectors (mosquitoes, ticks), water-borne infectious diseases and legionellosis.

The burden of disease due to climate change on other infectious diseases is yet to be determined, such as, for example, due to exposure to blue-green algae. This also applies to the burden of disease resulting from possible new emerging infectious diseases such as, for example, resistant fungi.

Climate threat

The currently known main climate threats to health risks related to infectious diseases are: rising temperatures and wetter weather (increased risk of flooding). Figure 8.1 shows the trend since 1901.

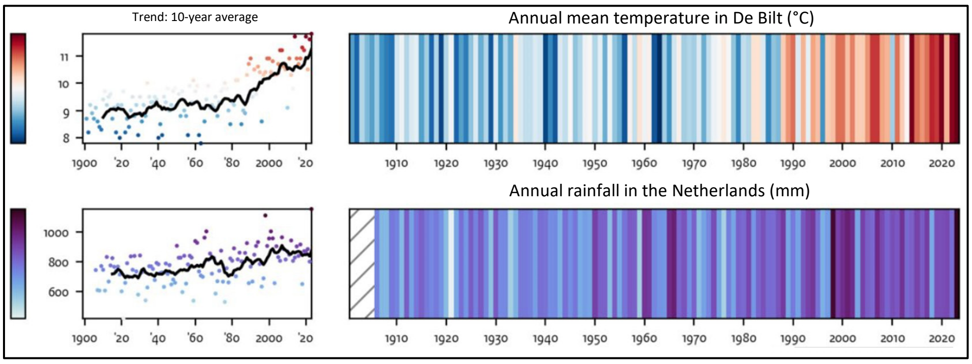


Figure 8.1 Annual mean temperature and annual rainfall are increasing (source: KNMI, 2023).

As far as currently known from reported studies, climate change could increase the burden of disease from more than half of all human infectious diseases worldwide (Mora et al., 2022). This is due both to effects on infectious diseases already present in a country and to possible effects on the emergence and establishment of new infectious diseases such as mosquito-borne diseases (Braks, De Roda Husman, 2013). The exact magnitude of these effects for the Netherlands is still unclear (Hall et al., 2021).

Mosquitoes
Climate change may cause the Dutch climate to become suitable or more suitable for the establishment of new mosquito species and the outbreak of new infectious diseases. For some species, such as the Asian tiger mosquito (*Aedes albopictus*), which can transmit dengue, zika and chikungunya viruses, the climate in the Netherlands is already suitable for settlement (Hall et al., 2021). In recent years, the Netherlands has faced several new mosquito-borne infectious diseases. An outbreak of a mosquito-borne virus among birds occurred for the first time in 2016 (Rijks et al., 2016). The indigenous house mosquito *Culex pipiens* is responsible for the circulation of both this Usutu virus and West Nile virus. The West Nile virus first appeared in the Netherlands in 2020 in both birds and mosquitoes and affected eight people.[70]

Monitoring of mosquitoes and birds and increasing awareness of the pattern of symptoms of West Nile fever[71] among doctors and citizens are crucial to further identifying this risk. The Asian tiger mosquito has not yet established itself in the Netherlands, but it regularly enters the country through the international transport of goods. The mosquito has already established itself in other parts of Europe, especially in countries around the Mediterranean and the Black Sea, but now also in areas closer to the Netherlands such as parts of Switzerland, Germany and northern France (ECDC & EFSA[72]). This development, combined with climate change, is increasing propagule pressure on the Netherlands. At the same time, international air travel has boomed, and with it the introduction of pathogens such as dengue virus by infected tourists.

[70] https://www.rivm.nl/westnijlkoorts
[71] https://www.rivm.nl/westnijlkoorts
[72] European Centre for Disease Prevention and Control and European Food Safety Authority. Mosquito maps [Internet]. Stockholm: ECDC; 2023. Available from: https://ecdc.europa.eu/en/disease-vectors/surveillance-and-disease-data/mosquito-maps

This creates (if a suitable vector is established) the risk of local outbreaks of, for example, dengue, as is already seen in France, Spain and Italy (ECDC[73]). With expected higher summer temperatures, this increases the future risk of local transmission of mosquito-borne infectious diseases in the Netherlands. However, according to the scenarios and timelines studied, the Dutch climate will not become warm enough for large-scale transmission of these diseases (Kraemer et al., 2019; Liu-Helmersson et al., 2016; Messina et al., 2019).

Ticks
On average, 20% of ticks are infected with the bacteria that can cause Lyme disease.[74] A tick bite can lead to transmission of this pathogen. Research on the effect of climate change on the tick population in the Netherlands over the past 20 years shows that the tick season now starts about a month earlier compared to the 1950s, but the tick population itself is not increasing (Hartemink et al., 2019).

Some human infections with tick-borne encephalitis virus[75] (TBE virus) have also been reported annually since 2016. Higher temperatures appear to promote the transmission of this virus (Daniel et al., 2018). More knowledge about Lyme disease among both recreational users and doctors could be a reason for the stabilisation of incidence.

Water
Vibrio bacteria occur in coastal waters and can cause health problems such as gastrointestinal symptoms or wound infections through the mouth (for example, by eating contaminated shellfish or ingesting contaminated water while swimming) or skin. In the extremely hot summer of 2006, a striking number of wound and ear infections were found in several European countries including the Netherlands (Schets et al., 2006). These were caused by exposure to *V. alginolyticus*. Climate change is warming sea water along the North Sea coast and is expected to increase the presence of *Vibrio* bacteria in sea water. This increases the risk of *Vibrio* species infection from recreation (Sterk et al., 2015).

Extreme precipitation in a short period of time can cause water to flood the streets. Runoff from dirty streets and possible sewer overflows create infection risks (gastrointestinal and respiratory infections) when coming into contact with the water (Mulder et al., 2019). Examples are *Campylobacter* and *Cryptosporidium* (Sterk et al., 2016).

During warmer summers, more bathing water-related symptoms are reported on average (Limaheluw et al., 2020). Health problems can arise from exposure to microbiologically contaminated bathing water, contaminated with human and animal faeces, untreated wastewater or excess of natural microorganisms (such as blue-green algae). As summers become increasingly hot, people may start to recreate more frequently in surface waters, including at unofficial bathing sites, where water quality is not monitored (Schets et al., 2022; Wegwijzer Wildzwemmen, 2023). The occurrence of blue-green algae at a site can

[73] https://www.ecdc.europa.eu/en/all-topics-z/dengue/surveillance-and-disease-data/autochthonous-transmission-dengue-virus-eueea
[74] https://www.rivm.nl/ziekte-van-lyme
[75] https://www.rivm.nl/tekenencefalitis

also contribute to this. This may also increase the burden of disease related to recreation in water.

Legionellosis
Legionellosis is an airborne infectious disease caused by *Legionella* bacteria. *Legionella*[76] bacteria grow in water with a temperature between 20 and 50 degrees Celsius and can be inhaled via mist. Clear associations have been found between the incidence of legionellosis and certain weather conditions, such as periods of dry and warm weather followed by rain (Pampaka et al., 2022; Brandsema et al., 2014). Increases in temperature and precipitation may have already increased conditions for growth of *Legionella* bacteria in the environment and related infection risks (Han, 2021). Warmer drinking water in the distribution system can lead to higher infection risks of certain opportunistic pathogens, including *Legionella* bacteria. In the case of *L. pneumophila*, which causes most cases of legionellosis, growth can occur in the drinking water distribution system if the water temperature is above 28 degrees Celsius for several days (KWR, 2020). For other pathogens, such as *Pseudomonas aeruginosa*, this limit is lower. The current maximum standard for drinking water temperature is 25 degrees Celsius. Due to climate change, exceedances of this standard may become more frequent in urban areas in the future (Agudelo-Vera et al., 2017).

So, in addition to these pathogens, there are other pathogens that could potentially come into play due to climate change.

Frequency
Ticks are present throughout the year and become active above 7 degrees Celsius. June and July see the highest number of tick bite reports.[77] Therefore, very few people are bitten in winter. However, with increasing temperatures in winter, ticks may already become active early in the year. This means the period when people can be bitten is getting longer.

Most mosquito nuisance occurs in the summer months. Mosquitoes reproduce faster under high temperatures. But even in winter, some mosquito species remain active and people get bitten. Studies are under way to identify which mosquitoes remain active in winter and whether they carry pathogens.[78]

Many waterborne pathogens depend on precipitation and outdoor and water temperatures (De Roda Husman, A.M., F.M. Schets, 2010). In addition, water recreation is an important exposure route. Therefore, they are often seasonal. In summer and late summer, water temperatures of the sea and other water bodies are highest and recreation is most frequent. A risk of infection by a *Vibrio* species will therefore mainly be present during the summer months (July–September). There is a clear link between days with temperatures of at least 25 °C and the incidence of symptoms. More people are also

[76] https://www.rivm.nl/legionella
[77] https://www.rivm.nl/nieuws/tien-jaar-tekenradar-80000-tekenbeetmeldingen-kans-op-tekenbeet-in-drenthe-grootst
[78] https://www.naturetoday.com/intl/nl/observations/mosquito-radar

expected to experience health problems from recreation in controlled and uncontrolled surface waters due to climate change (Limaheluw et al, 2020; Schets et al, 2022 Wezenberg-Hoenderkamp and Floor, 2020).

The Netherlands will very likely experience more frequent extreme rain showers resulting in water on the streets or flooding. However, how often these conditions will occur is still uncertain. Therefore, it is also difficult to predict whether this will be followed by outbreaks of infectious diseases.

The number of reports of pneumonia caused by *Legionella* has increased over the past 10 years[79] (Figure 8.2). The increase was seen in several regions of the country and is likely related to certain weather conditions favourable to growth and spread of *Legionella* from environmental sources (Klous et al., 2022). These weather conditions could occur more frequently due to climate change and thus cause more infections.

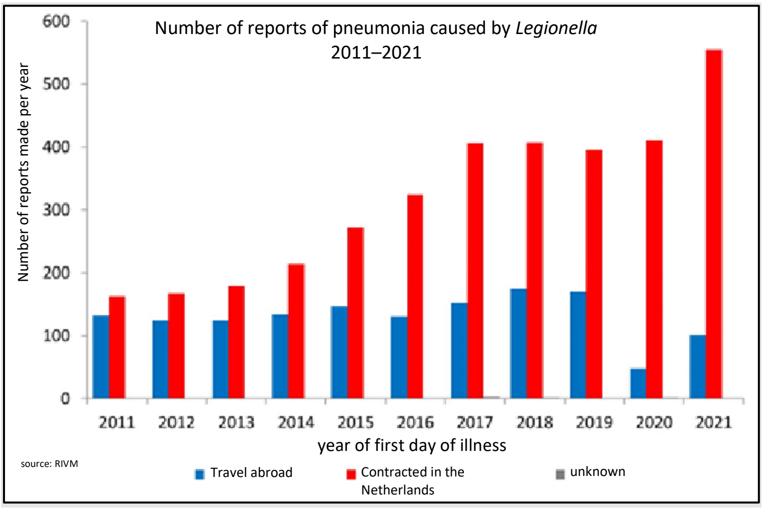


Figure 8.2 Number of reports of pneumonia caused by Legionella (source: RIVM).

Secondary effects
Following the 2021 floods in Limburg, Germany and Belgium, potential infection risks have been identified by the European Centre for Disease Prevention and Control (ECDC, 2021). This indicated possible increased risks for, for example, leptospirosis.[80] Damage to infrastructure, disrupted healthcare and reduced ability to maintain distance due to evacuations, etc., may also lead to increased risks of infectious diseases (and outbreaks of these diseases).

Exposure
Infectious diseases are caused by a combination of factors: (1) presence of the pathogen, (2) the right conditions or combination of conditions for multiplication and (3) human or animal exposure.

[79] https://www.rivm.nl/legionella
[80] https://www.rivm.nl/leptospirose

Potential exposure to the vector-borne infectious diseases listed here is almost the same for everyone. Mosquitoes and ticks are everywhere. Whether actual exposure occurs depends on whether people spend time in green areas or have a garden, for example. Mosquitoes lay their eggs in standing water. Ticks are also found everywhere and are mainly found in tall grass or among dead leaves, preferably near trees or bushes. Every year, over 1.5 million people are bitten by a tick.[81] The risk of getting a tick bite is slightly higher in areas with lots of greenery, such as a forest or a park. Climate change has increased the number of warm days, which may mean that people are going outside more and may be more exposed to ticks.

Exposure to waterborne infectious diseases can occur through swimming or recreation in seawater or other water containing pathogens. Here, too, exposure can only take place when a person actually comes into contact with seawater or other water. Exposure to water on the street after heavy rain or a flooded area can of course only occur after these extremes. Children often tend to play in this water, increasing the risk of exposure to waterborne infectious diseases. So this should be avoided.

Exposure to *Legionella* often comes from a defined source. In case of an outbreak, potentially only a limited number of people are exposed. However, some sources of *Legionella* bacteria, such as wastewater treatment plants or cooling towers, can cause exposure over long distances (up to at least 10km from the source).

Geography
Mosquitoes and ticks are found everywhere in the Netherlands. The density of tick presence does vary.[82] Most tick bite reports came from Gelderland followed by North Brabant and North Holland (Figure 8.3). Relatively speaking, most tick bites per capita are reported in Drenthe, and the least in South Holland.[83] Invasive exotic mosquitoes are monitored at places where they may enter the Netherlands via imported goods or travellers.

[81] https://www.rivm.nl/vragen-en-antwoorden-tekenbeten-en-lyme
[82] https://www.utwente.nl/en/news/2019/10/63588/university-of-twente-maps-out-ticks-in-the-netherlands
[83] https://www.rivm.nl/nieuws/tien-jaar-tekenradar-80000-tekenbeetmeldingen-kans-op-tekenbeet-in-drenthe-grootst

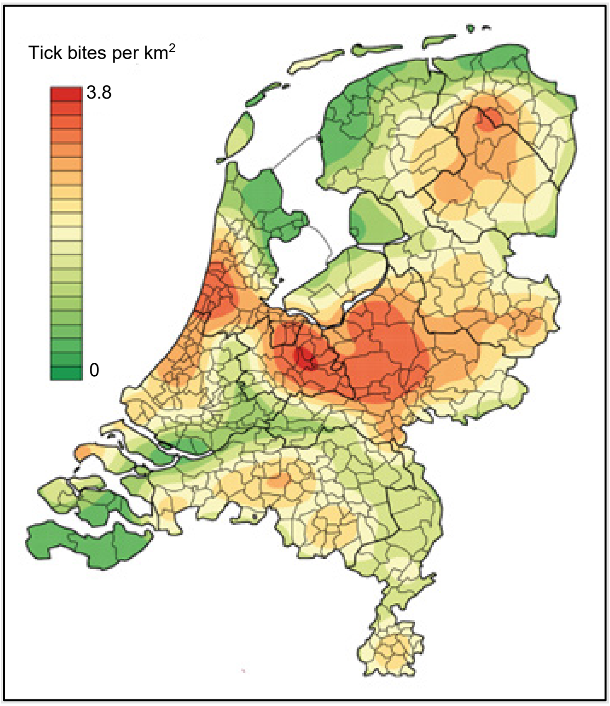


Figure 8.3 This map shows where most tick bites are reported via Tekenradar (Tick Radar). These areas are not only home to many ticks, but also to many people (source: Tekenradar.nl).

Places where more people live and/or recreate are also likely to have a higher risk of a tick bite. So the geographical differences in tick bites are mainly related to the behaviour or presence of people. Also, when it comes to tick bites, children playing outdoors, green space workers and campers/green space recreational users have a higher risk of being bitten by a tick due to higher exposure to greenery. Research on ticks, tick bites and prevention of Lyme disease is still in full swing.

Waterborne infectious diseases are restricted to coastal waters, surface waters and flooded areas. People living in areas prone to flooding from rivers or water on the streets are more vulnerable to waterborne infectious diseases. Flood cleaners are also particularly vulnerable to exposure.

The risk of airborne infectious disease may be increased near certain sources. Because of increasing sustainability, biogas is extracted from wastewater, for example. The risk of *Legionella* infection is higher near such wastewater treatment plants (WWTPs) (Vermeulen et al., 2019).

Relevant indicators:

- *Vibrio* in shellfish (limited monitoring by RIVM on behalf of the Netherlands Food and Consumer Product Safety Authority (NVWA));
- tick bites (tekenradar.nl);
- tick distribution (Tick maps (europa.eu)).

Susceptibility

In general, children, the elderly and the chronically ill are more susceptible to infectious diseases. The highest incidence of Lyme disease is reported in children (5–14 years). It has not been scientifically proven that people with reduced immunity are more likely to contract Lyme disease.[84] Severe pneumonia after legionellosis is more common in the elderly, people with impaired immunity due to, for example, chronic illness, people taking anti-inflammatory drugs and smokers.[85]

Adaptive capacity

Behaviour is an important factor in the risk of contracting infectious disease. For mosquitoes and ticks, it is important to cover your skin to reduce the chances of being bitten. With ticks, it is important to check yourself for tick bites, especially after exposure to greenery.

To reduce mosquito nuisance around the house, it is important to make sure there is no standing water around the house where mosquitoes can lay their eggs. There are also insect-repellent measures such as mosquito nets or using an insect repellent on the skin.

The Netherlands Food and Consumer Product Safety Authority (NVWA) fights exotic mosquitoes and ensures that companies comply with the rules.[86] Monitoring the locations where the exotic mosquitoes are found and then controlling them will prevent them from settling in the Netherlands.

Water bodies or water storage sites are often used in public spaces as climate adaptation measures. It is important that this water be kept in motion to prevent mosquitoes from laying eggs on the water surface.

For safe bathing, there are designated bathing spots that are regularly checked for pathogens during the bathing season. Bathing in controlled waters reduces the risk of infectious diseases. Communication about bathing water quality and use and any applicable warnings, negative bathing advisories or bathing bans is a task of the provinces. This includes the use of the website zwemwater.nl and information boards at bathing locations. When implementing new water concepts, the *Waterkwaliteitscheck* (Water Quality Check)[87] can be used to identify potential infection risks and what measures can be taken to reduce these risks.

For *Legionella* bacteria, there are advisories and legal guidelines (in the case of cooling towers and certain collective tap water systems such as those of hospitals, for example) that are designed to reduce infection risks. The maximum standard for drinking water temperature is 25 degrees Celsius, and adherence to this standard may reduce the infection risks of drinking water due to climate change (KWR, 2020).

There is increasing demand from practice on how climate adaptation measures can be properly deployed. Moreover, the focus is on reducing potential risks that may arise from, for example, green and blue adaptation measures on pathogens. More insight into the contributing conditions and related risks can be found in the *Waterkwaliteitscheck*

[84] https://lci.rivm.nl/richtlijnen/lymeziekte
[85] https://www.rivm.nl/legionella
[86] https://www.nvwa.nl/onderwerpen/muggen-knutten-en-teken
[87] https://waterkwaliteitscheck.nl/home

(Water Quality Check)[88] and the *Kennisportaal Klimaatadaptatie* (Climate Adaptation Knowledge Portal).[89]

Impact

The burden of disease from infectious diseases prevalent in the Netherlands varies from year to year. In 2018, the burden of disease from studied infectious diseases was just under 10% of the total burden of disease in the Netherlands. Influenza (flu) is usually the leading cause of the burden of disease from infectious diseases (10,200 DALYs[90] in 2021).

In comparison, the burden of disease from COVID-19 in 2021 has been estimated at 218,900 DALYs (RIVM, 2022). In 2021, 2,981 people died of infectious and parasitic diseases (infectious disease indication). Nearly 20,000 people[91] died from COVID-19.

In general, the elderly and the chronically ill are more susceptible to infectious diseases.

The burden of disease from the infectious diseases discussed here is not always known.
There are infectious diseases that are climate sensitive and that already infect and/or kill many people in the current situation. However, there are no figures on the role of climate change in this.

Mosquito-borne infectious diseases
A contracted West Nile virus infection was detected in humans in the Netherlands for the first time in 2020. In 80% of people, West Nile fever, caused by West Nile virus, does not produce symptoms. In 20% of cases, mild flu-like symptoms occur, and 1% can develop a severe course, such as inflammation of the brain or meningitis.[92] Severe symptoms resulting in death occur for 1 in 7 to 1 in 25 people (4%–14%).[93] No new local cases of this or other mosquito-borne infectious diseases have been reported since 2020, although West Nile virus has still been found incidentally in birds. In the context of climate change, the main focus is on mosquitoes of the genus *Aedes*. Depending on the species, these mosquitoes can act as vectors of, for example, dengue, chikungunya or zika virus.

Lyme and tick-borne encephalitis virus
Every year, about 27,000 people contract Lyme disease, which is transmitted by ticks. The incidence of Lyme disease increased sharply between 1993 and 2009 (from 39 to 134 per 100,000 people) but seems to have stabilised in recent years (Figure 8.4). However, despite information campaigns and increased awareness about the risks of ticks and tick bites, no decline has been seen yet. The clinical picture of Lyme disease varies (from fever to joint pain) and can be treated

[88] https://waterkwaliteitscheck.nl/home
[89] https://klimaatadaptatienederland.nl/kennisdossiers/stedelijke-waterkwaliteit/
[90] DALY: Disability Adjusted Life Years. Measure for the burden of disease in a population; composed of years of life lost (due to premature death) and years lived with health problems (for example, disease), weighted for severity.
[91] https://www.vzinfo.nl/infectieziekten/sterftecijfers
[92] https://www.rivm.nl/westnijlkoorts
[93] Figures at https://www.rivm.nl/westnijlkoorts

early on with antibiotics. If undetected and not treated with antibiotics, Lyme disease can lead to long-term complications (joint, skin, nerve or heart problems).[94] The burden of disease from vector-borne infectious diseases is almost entirely attributable to Lyme borreliosis and amounted to about 2,200 DALYs in 2017 (de Gier et al., 2018).

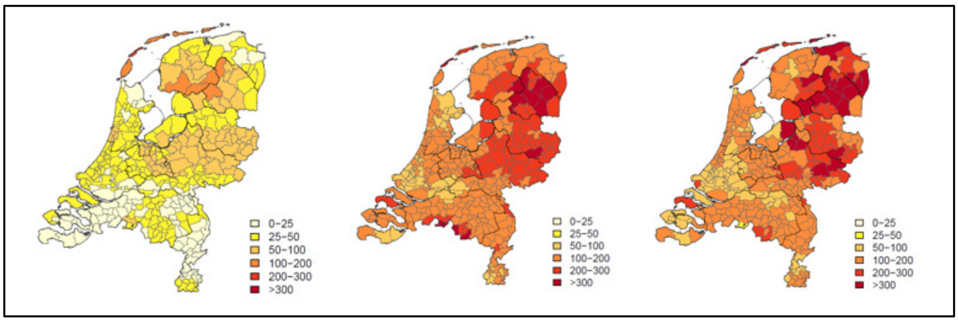


Figure 8.4 Number of Lyme diagnoses with red spot/ring in 1994, 2017 and 2021 per 100,000 residents (source: https://www.tekenradar.nl/).

Tick-borne encephalitis virus[95] can cause an inflammation of the brain or meningitis and can have a severe course in rare cases. People with these severe symptoms die very rarely from this disease: about 1–2% of patients with an inflammation of the brain or meningitis die. Some of these patients retain residual neurological symptoms after the infection. Only 1 in 1,500 ticks is infected with this virus; in 2020, 5 people contracted the TBE virus.[96] There are no specific drugs against tick-borne encephalitis. There is, however, a vaccine that gives 95% protection. People who spend long periods of time in areas where tick-borne encephalitis is common can get vaccinated.

Vibrio and waterborne infectious diseases
Contact with water on the street poses increased risks for gastrointestinal and respiratory infections (Mulder, 2021). An infection with *Vibrio* bacteria can cause health problems such as gastrointestinal problems or wound infections. In total, in 2017, 2018 and 2019, there were 323 reports of health problems after swimming that involved a total of 1,093 patients (Limaheluw et al., 2020). The types of health problems (and their distribution) reported as a result of water recreation have remained roughly the same since they started being tracked (through the Bathing Water Survey). The most frequently reported health problems following water recreation are skin problems (65%), followed by gastrointestinal problems (19%). Another 6% had skin problems as well as gastrointestinal problems. The remaining 10% had other symptoms. Other symptoms include, for example, headaches and fever (Limaheluw et al., 2020).

Legionella
In 2021, there were 556 reports of *Legionella* pneumonia contracted in the Netherlands, compared to around 170 reports in 2011. So there is an upward trend. In 2021, 29 people died from the infection. Symptoms of a *Legionella* infection are flu-like symptoms. Sometimes, an infection

[94] https://www.rivm.nl/ziekte-van-lyme
[95] https://www.rivm.nl/tekenencefalitis
[96] https://www.rivm.nl/tekenencefalitis

causes severe pneumonia that can kill people. In 2021, the burden of disease from legionellosis was 9,300 DALYs.

Relevant indicators (source):
- health problems after water recreation (RIVM);
- legionellosis: incidence, mortality and morbidity (RIVM);
- West Nile fever: incidence, mortality (RIVM, or climatic suitability (according to Lancet Countdown));
- tick-borne encephalitis virus: incidence, mortality and morbidity (NIVEL, RIVM);
- Lyme disease: incidence, mortality and morbidity (NIVEL, RIVM);
- non-cholera *Vibrio*: suitability of coastline (Lancet Countdown).

Cascade effects

An infectious disease outbreak can have a major impact on society (see Wildcards).

Final impact: people

An affected person is defined here as infected with the infectious disease. Symptoms can be absent or range from mild to severe.
For most infectious diseases, including most climate-sensitive infectious diseases, the contribution of climate change is not known and the final impact cannot be estimated.

Mosquito-borne infectious diseases
West Nile virus infections were detected for the first time in the Netherlands in 2020 (seven infections). Since then, no new locally acquired cases of mosquito-borne infectious disease have been reported. At least one death from West Nile fever requires an outbreak in which about 700 to 2,500 people are seriously ill. This would then require a total of 7,000 to 25,000 people to be infected. In the Netherlands, these numbers are not yet in sight. Other mosquito-borne infectious diseases (dengue, chikungunya or zika virus) also fail to achieve these kinds of infection numbers. The final impact is therefore low (<10,000 affected persons).

Lyme and tick-borne encephalitis virus
Climate change means a longer tick season and likely more outdoor recreation. Every year, 27,000 people contract Lyme disease. It is not known what proportion of this is a contribution from climate change. The final impact is estimated to be medium (10,000–100,000 affected persons).

Five persons suffered from tick-borne encephalitis in 2020; in previous years (2016–2019), it was one to two patients per year. The final impact is therefore low (<10,000 affected persons).

Vibrio and waterborne infectious diseases
In the Netherlands, there is no reporting requirement for non-cholera *Vibrio* infections, so there is no real insight into any trends in disease cases, and therefore no estimate of the contribution of climate change over the period 1991–2020. Therefore, no statement can be made about the final impact.

The number of reported health problems after bathing is relatively low for the number of people who bathe in open water. This is likely due to the relatively mild symptoms that people do not report. The actual number of affected persons is expected to be higher. There is a clear link between days with temperatures of at least 25 °C and the incidence of symptoms. The number of days with temperatures of at least 25 °C has increased due to climate change, therefore also resulting in more affected persons. The final impact is at low (<10,000 affected persons) according to the recorded figures but could very well be at medium (10,000–100,000 affected persons).

Legionella
Based on reports, the incidence of *Legionella* pneumonia in the Netherlands was 0.27 per 100,000 population between 1987 to 1998. In the period 1999–2000, the incidence rate (excluding the Bovenkarspel cases) rose to 0.91 per 100,000 residents (Schets and De Roda Husman, 2004). From 2007 to 2014, the incidence rate hovered around 2 per 100,000 before rising further to above 3 per 100,000.[97] The rise in *Legionella* incidence could well be explained by climate change. The conditions in which *Legionella* bacteria occur have become more favourable (warmer and wetter). Based on the number of deaths, the final impact is medium (10–100 deaths).

Final risk: economy
Every year, infectious diseases cause healthcare costs. Healthcare spending on infectious diseases in 2019 was estimated at over €1.4 billion, amounting to 1.5% of total healthcare spending in the Netherlands.[98] Besides healthcare costs, there are also costs related to loss of working hours. This in turn affects the sectors where these people work. The total economic damage caused by infectious diseases is unknown.

The economic impact of emerging infectious diseases can be large. However, it is difficult to make an estimate for that. For the COVID-19 pandemic, the expenditure was very high (€82.9 billion according to the Netherlands Court of Audit, 2023). A limited number of infections of, say, West Nile virus with mild symptoms will not result in much cost. Societal costs for Lyme disease were determined for the first time in 2017 (van den Wijngaard et al., 2017). The disease is costing €20 million a year. Excluding pandemic outbreaks, the estimate for the final risk to the economy for infectious diseases, bearing in mind the share of climate change, is low (< €100 million per year).

Likelihood
Climate change may worsen existing infectious diseases and allow new infectious diseases to emerge. An effect of climate change has already been identified for several infectious diseases, such as infections caused by *Vibrio*. How often and at what scale of spread new infectious diseases will emerge is difficult to determine. The likelihood is expected to increase, but the frequency is different for each infectious disease.

[97] https://www.vzinfo.nl/infecties-van-de-onderste-luchtwegen/leeftijd-en-geslacht/legionella
[98] https://www.vzinfo.nl/infectieziekten/sterftecijfers

Wildcards & tipping points

Wildcards and tipping points are potentially relevant for emerging infectious diseases and vectors. When a new invasive vector species establishes itself in the Netherlands, it can be called a tipping point. A clear example of a wildcard is the emergence and outbreak of a new infectious disease. The emergence of certain emerging zoonoses (infectious diseases that can be transmitted from animals to humans) is likely to be facilitated by climate change (see International aspects).

Pandemic
A pandemic can be classified under the wildcard section because the consequences are very large. There have been several pandemics in the past 30 years, the impact of which has been limited in the Netherlands. Examples are SARS, swine flu and Ebola. COVID-19 was an exception to this. The COVID-19 pandemic shows the impact of a pandemic infectious disease. Climate change may increase the risk of a pandemic such as COVID-19, for example due to migration flows of people as residential areas become unliveable. But animals are also moving to other habitats due to climate change (such as bats in China), making transmission of viruses to humans suddenly possible due to increased exposure.[99] The World Economic Forum estimates that a pandemic such as COVID-19 could occur once every 50 years.[100]

The pressure on the healthcare system was very high. Strict measures were in place to prevent spread, and almost all sectors in the country were affected. The protective equipment used during the COVID-19 pandemic (including face masks) had a high environmental impact (RIVM, 2023).

Administrative situation

Climate adaptation measures can affect infection risks but are usually not specifically targeted to do so. More green and blue areas in the living environment can affect infection risks (for example, Schets et al., 2022). Municipalities are usually responsible for these measures. Water boards may also be involved in water system measures. Among others, Municipal Public Health Services (GGDs) and RIVM advise on infection risks and how to deal with them; see for example the *Waterkwaliteitscheck*.[101] The Netherlands Food and Consumer Product Safety Authority (NVWA) is responsible for controlling invasive mosquito species. National coordination of large-scale and other outbreak control lies with RIVM in collaboration with the GGDs and the Netherlands Municipal Public Health Services and Medical Assistance in Accidents and Disasters (GGD GHOR).

Coherence with other transitions and policies

RIVM is conducting research into the potential impact of mitigation measures as part of the energy transition on infectious diseases.

[99] https://www.knmi.nl/over-het-knmi/nieuws/covid-19-epidemie-veroorzaakt-door-klimaatverandering
[100] https://www.weforum.org/agenda/2021/09/pandemics-epidemics-disease-covid-likelyhood/
[101] https://waterkwaliteitscheck.nl/home

International aspects

Establishment of invasive vector species in surrounding countries/territories increases the propagule pressure of these species in the Netherlands. West Nile virus has long been prevalent in south-eastern Europe and the Mediterranean. A record number of people in Europe were infected with West Nile fever in 2018. This outbreak was likely due to the very high temperatures and the presence of many mosquitoes and birds that spread the virus.[102]

The ECDC,[103] through a reporting system by Member States (TESSy), records new cases of common infectious diseases within Europe. VectorNet,[104] another ECDC project, focuses directly on monitoring the spread of vectors.

Climate change may also affect the emergence of new infectious diseases. Most emerging infectious diseases in humans have an animal origin (zoonosis). Due to climate change, combined with other developments such as urbanisation, animals increasingly need to find new suitable habitats. During these migrations, animal species may encounter each other for the first time, and new exchanges of pathogens may take place (spillover) (Carlson et al., 2022). This will also increase the chances of a new zoonosis emerging. Key hotspots for this development, such as Central Africa or Southeast Asia, are regions that are also home to many people and are experiencing rapid population growth. This increases the likelihood of human-animal interactions and the spread of a new infectious disease (Carlson et al., 2022). The COVID-19 pandemic showed that the Netherlands is also vulnerable to emerging infectious diseases.

The consequences of a new infectious disease (which originated outside the Netherlands) can also be significant in the Netherlands (COVID-19, for example). Climate change affects the emergence of new infectious diseases. When an invasive mosquito species establishes itself in surrounding areas, control and prevention of establishment in the Netherlands becomes more difficult.

International transport allows vectors to spread internationally.
For example, the eggs of the Tiger mosquito are widespread over large parts of the world and hatch on contact with water.[105]
Relevant indicators (source):

- spread of mosquitoes (ECDC[106]) or climatic suitability for specific mosquito species (for example, *Ae. Albopictus*).

Maladaptation and/or lock-ins

Green adaptation measures, for example, can affect risks of tick-borne infectious diseases. Greening in cities and green linking zones, for

[102] https://www.rivm.nl/westnijlkoorts
[103] European Centre for Disease Prevention and Control https://www.ecdc.europa.eu/en
[104] https://www.ecdc.europa.eu/en/about-us/partnerships-and-networks/disease-and-laboratory-networks/vector-net
[105] https://www.rivm.nl/veelgestelde-vragen-over-aziatische-tijgermug
[106] European Centre for Disease Prevention and Control and European Food Safety Authority. Mosquito maps [Internet]. Stockholm: ECDC; 2023. Available from: https://ecdc.europa.eu/en/disease-vectors/surveillance-and-disease-data/mosquito-maps

example within the context of climate adaptation, should certainly also take into account the occurrence of ticks (van Acker et al., 2019). Blue adaptation measures (water storage or water bodies) involve risks of waterborne infectious diseases.

Starting points for adaptation policy

RIVM and Municipal Public Health Services (GGDs) advise on potential infection risks related to adaptation measures and how to mitigate them. The overall positive effects of adaptation measures on health (when designed and implemented with consideration of infection risks) are also positive in the context of infectious diseases. These positive effects may be greatest for vulnerable groups (Limaheluw et al., 2023).

Equity

Vulnerable groups as described in the 'Susceptibility' section are usually more susceptible to illness or severe illness after infection. Vulnerability can also occur due to higher exposure or higher exposure risk, such as in people who often participate in recreation in water/green spaces or perform clean-up activities after a flood. In certain occupational groups, potential exposure to vectors or certain pathogens will also be higher, such as green space management, the agricultural sector or wastewater treatment.

Climate adaptation measures (green and blue) can improve overall health and thus also reduce the risk of infectious diseases: on the one hand, by reducing vulnerability to the effects of climate change such as heat and flooding; and on the other hand, through the positive health effects of green and blue areas on physical and mental health. Relatively speaking, these positive effects will be greatest for people with lower access to other health-promoting facilities.

Besides positive effects, climate adaptation measures can also pose infection risks. More green and blue areas in the living environment can lead to more exposure to ticks or waterborne pathogens, for example. These risks can be mitigated (see Adaptative capacity).

Transparency, aggregation and delineation

The data for determining the climate threat is based on quantitative data, measured and modelled by KNMI. The data on the occurrence and frequency of infectious diseases is quantitative. Data on exposure is partly quantitative (for example, the amount of ticks and tick bites), and a lot of research (quantitative and qualitative) is still ongoing. Data on susceptibility is based on quantitative studies (incidence data). Information on adaptive capacity is mainly qualitative data. Data on impact is based on quantitative data (type of health problems, diagnoses, etc.). The final impact is based on disease burden estimates using quantitative data as a source.

Knowledge gaps

Many of these knowledge gaps are described in the report by Van der Ree et al. (2022). It found that a better picture is needed of the climate sensitivity of pathogens and infectious diseases (directly and indirectly), of the current and future risks of, and the burden of disease from, climate-sensitive infectious diseases and of the impact of climate change on these risks/this burden of disease (quantitatively).

Uncertainty and reliability

There is no complete picture of the current burden of disease from infectious diseases. This is partly because, for most infectious diseases, there is no reporting requirement and because many infectious diseases are often mild and do not require follow-up diagnostic testing. Available disease burden estimates have been made based on internationally accepted methods (very high reliability and virtually certain). Some effects of climate change on infectious diseases that are also relevant in the Netherlands (for example legionellosis) are already being observed in other countries. Specifically for the Netherlands, except for ticks, no retrospective study on the long-term or other effect of climate change on these diseases has yet been done. Reliability and uncertainty about relevant exposure pathways and vulnerable groups is very high and in most cases very likely.

As was also previously found in Hall et al. (2021), among others, climate sensitivity of diseases and pathogens as described here is usually quite certain (very likely and very high reliability). This means that expectations about the direction of a change are also certain (for example, increased risk with rising temperatures). However, the magnitude of future risks (and whether a new risk will materialise) is often uncertain, partly because of insufficient understanding of the current burden of disease, the complex mechanisms leading to climate sensitivity, and the linkages with and influence of other developments.

Expert assessment

RIVM experts are involved in research proposals as well as reports and other publications on the topic and are aware of the latest literature and studies. Both internally and externally, they are involved in various working groups and national and international collaborations on the topic. Expert judgement has therefore been used extensively for this fact sheet.

As there is much integrality in health effects between the topics, the aim was to have all topic experts (or their substitutes) present during the expert sessions. PBL also regularly attended these sessions, including the expert session to determine uncertainty and reliability.

Infectious diseases fact sheet references

Agudelo-Vera, C.M., Blokker, M., Kater, H. de, and Lafort, R. (2017). Identifying (subsurface) anthropogenic heat sources that influence temperature in the drinking water distribution system. Drink. Water Eng. Sci., 10, 83-91. https://doi.org/10.5194/dwes-10-83-2017

Algemene Rekenkamer (2023), Coronarekening – mei 2023 (editie 8)

Bekedam H., Arjan Stegeman, Fred de Boer, Ron Fouchier, Jan Kluytmans, Sander Koenraadt, Thijs Kuiken, Wim van der Poel, Ria Reis, Gerdien van Schaik, Leo Visser (2021). Zoönosen in het vizier. Rapport van de expertgroep zoönosen, 2021.

Braks, M.A.H., de Roda Husman A.M. (2013). Dimensions of Effects of Climate Change on Water-Transmitted Infectious Diseases. Air Water Borne Diseases 2: 109. doi:10.4172/2167-7719.1000109

Brandsema, PS, Euser SM, Karagiannis I, Den Boer JW, Van Der Hoek W. (2014). Summer increase of Legionnaires' disease 2010 in The Netherlands associated with weather conditions and implications for source finding. Epidemiology and Infection. 2014;142(11):2360-71

Carlson, CJ, Albery GF, Merow C, Trisos CH, Zipfel CM, Eskew EA, et al. (2022). Climate change increases cross-species viral transmission risk. Nature. 2022;607(7919):555-62.

Daniel, M., Danielová, V., Fialová, A., Malý, M., Kříž, B. and Nuttall, P.A. (2018). Increased relative risk of tick-borne encephalitis in warmer weather. Frontiers in Cellular and Infection Microbiology. 2018 Mar 22;8:90. DOI: 10.3389/fcimb.2018.00090

De Gier, B., Mooij, S.H., Hahné, S.J.M. (2018). Staat van infectieziekten in Nederland, 2017. RIVM Rapport 2018-0032

De Roda Husman, A.M., F.M. Schets (2010). Climate change and recreational waterrelated infectious diseases. Report 330400002/2010
ECDC (2021). Extreme rainfall and catastrophic floods in western Europe. Rapid risk assessment.

Hall, E.F., R.J.M. Maas, J. Limaheluw, C.D. Betgen (2021). Mondiaal klimaatbeleid: gezondheidswinst in Nederland bij minder klimaatverandering. RIVM Rapport 2020-0200

Han, XY (2021). Effects of climate changes and road exposure on the rapidly rising legionellosis incidence rates in the United States. PloS ONE 16(4): e0250364. https://doi.org/10.1371/journal.pone.0250364

Hartemink, N., Vliet, A. van, Sprong, H., Jacobs, F., Garcia-Martí, I., Zurita-Milla, R. and Takken, W. (2019). Temporal-Spatial Variation in Questing Tick Activity in the Netherlands: The Effect of Climatic and Habitat Factors. Vector-Borne and Zoonotic Diseases. Jul 2019.494-505.

Klous, G., Mcdonald, S., Boer, P. de, Hoek, A.J. van, Franz, E., Rooijen, M. van (2022). Staat van Infectieziekten in Nederland 2021. RIVM rapport 2022-0141

Kraemer, MUG, Reiner RC, Brady OJ, Messina JP, Gilbert M, Pigott DM, et al. (2019). Past and future spread of the arbovirus vectors Aedes aegypti and Aedes albopictus. Nature Microbiology. 2019;4(5):854-63.

KWR (2020). Invloed van temperatuur op groei van opportunistische ziekteverwekkers in drinkwater. BTO 2020.036 | Juli 2020

Limaheluw, J., Roda Husman, A.M. de en Schets, F.M. (2020). Gezondheidsklachten door waterrecreatie in de zomers van 2017, 2018 en 2019. Infectieziekten Bulletin, 31(1).

Limaheluw, J., AJ Versteeg-de Jong, JV Zwartkruis, JA de Kraker (2023). Lessen uit de COVID-19-pandemie voor het Nederlandse klimaatbeleid. RIVM-rapport 2022-0136

Liu-Helmersson J, Quam M, Wilder-Smith A, Stenlund H, Ebi K, Massad E, et al. (2016). Climate Change and Aedes Vectors: 21st Century Projections for Dengue Transmission in Europe. EbioMedicine. 2016;7:267-77.

Messina, JP, Brady OJ, Golding N, Kraemer MUG, Wint GRW, Ray SE, et al. (2019). The current and future global distribution and population at risk of dengue. Nature Microbiology. 2019;4(9):1508-15.

Mora, C., Tristan McKenzie, Isabella M. Gaw, Jacqueline M. Dean, Hannah von Hammerstein, Tabatha A. Knudson, Renee O. Setter, Charlotte Z. Smith, Kira M. Webster, Jonathan A. Patz & Erik C. Franklin (2022). Over half of known human pathogenic diseases can be aggravated by climate change. Nat Clim Chang: 12: 869-875 https://doi.org:10.1038/s41558-022-01426-1

Mulder, A.C., Pijnacker, R., de Man, H. et al. (2019). "Sickenin' in the rain" – increased risk of gastrointestinal and respiratory infections after urban pluvial flooding in a population-based cross-sectional study in the Netherlands. BMC Infect Dis 19, 377 (2019). https://doi.org/10.1186/s12879-019-3984-5

Pampaka D, Gómez-Barroso D, López-Perea N, Carmona R, Portero RC. (2022). Meteorological conditions and Legionnaires' disease sporadic casesa systematic review. Environmental Research. 2022 2022/11/01/;214:114080.

Rijks, J.M., Kik, M.L., Slaterus, R., Foppen, R., Stroo, A., IJzer, J., Stahl, J., Gröne, A., Koopmans, M., Jeugd, H.P. van der, Reusken, C. (2016) Widespread Usutu virus outbreak in birds in the Netherlands, 2016. Euro Surveillance. 2016 Nov 10;21(45):30391. DOI: 10.2807/1560-7917.ES.2016.21.45.30391

RIVM (2022). Staat van Infectieziekten in Nederland 2021.

RIVM (2023). Het effect van persoonlijke beschermingsmiddelen op het milieu. Casus mondkapjes.

Schets, F.M. en de Roda Husman, A.M. (2004). Gezondheidsaspecten van Legionella in water. RIVM-rapport 330000004/2004.

Schets, F.M., A. van der Wal, K. van Zoonen, A. Tholen, A.M. de Roda Husman (2022). Veranderingen in de inrichting van de leefomgeving maken aandacht voor infectieziekten urgent. RIVM-rapport 2021-0025.

Schets, F. M., van den Berg, H. H., Demeulmeester, A. A., van Dijk, E., Rutjes, S. A., van Hooijdonk, H. J., & de Roda Husman, A. M. (2006). Vibrio alginolyticus infections in the Netherlands after swimming in the North Sea. Euro surveillance, 11(11), E061109.3. https://doi.org/10.2807/esw.11.45.03077-en

Sterk, A., Schets, F.M., Roda Husman, A.M. de, Nijs, T. de, Schijven, J.F. (2015). Effect of Climate Change on the Concentration and Associated Risks of Vibrio Spp. In Dutch Recreational Waters. Risk Anal 35(9): 1717-1729. DOI: 10.1111/risa.12365

Sterk, A, Schijven J, de Roda Husman AM, de Nijs T. (2016). Effect of climate change on runoff of Campylobacter and Cryptosporidium from land to surface water. Water Res. May 15;95:90-102. Doi: 10.1016/j.watres.2016.03.005. Epub 2016 Mar 2. PMID: 26986498.

VanAcker, M.C., Little, E.A.H., Molaei, G., Bajwa, W.I., Diuk-Wasser, M.A. (2019). "Enhancement of risk for lyme disease by landscape connectivity, New York, New York, USA (United States of America)." Emerging Infectious Diseases 25(6): 1136-1143.

Van den Wijngaard, Cees. C., Agnetha Hofhuis, Albert Wong, Margriet G. Harms, G. Ardine de Wit, Anna K. Lugnér, Anita W. M. Suijkerbuijk, Marie-Josée J. Mangen, Wilfrid van Pelt (2017). The cost of Lyme borreliosis, European Journal of Public Health, Volume 27, Issue 3, June 2017, Pages 538–547, https://doi.org/10.1093/eurpub/ckw269

Van der Ree, J., C. Betgen, C. Boomsma, A. van Dijk, L. Hall, D. Houweling, J. Limaheluw, K. Rijs (2022). Plan van aanpak Onderzoeksprogramma Klimaatverandering en gezondheidseffecten. RIVM-rapport 2022-0030

Vermeulen, LC, Brandsema, PS, van de Kassteele, J, Bom, BCJ, Sterk, HAM, Sauter, FJ, van den Berg HHJL, de Roda Husman, AM. (2019). Atmospheric dispersion and transmission of Legionella from wastewater treatment plants: A 6-year case-control study. Int J Hyg Environ Health. 2021 Aug;237:113811. Doi: 10.1016/j.ijheh.2021.113811. Epub 2021 Jul 23. PMID: 34311418.

Wegwijzer wildzwemmen (2023). Testversie extern. Via Helpdesk water https://www.helpdeskwater.nl/@280100/wegwijzer-wildzwemmen/

Wezenberg-Hoenderkamp, K., Floor C. (2020). Buitenzwemwater in de gemeente Utrecht. Utrecht: Mulier Instituut; 2020.

9 Overview of final impacts

This report describes current climate risks and impacts on health in line with PBL's methodology and elaboration. As the information is analysed in fact sheets, information can be exchanged between the sectors.

The final impact on people in terms of health effects due to climate change is high when it comes to the climate-related topics of heat, air quality, mental health, UV radiation and pollen allergies. Regarding these topics, many people are affected and/or deaths occur. For infectious diseases, the impact ranges between low and medium or is unknown (see Table 9.1). Climate change has already contributed to the health effects of these climate-related topics over the past period from 1991–2020. Often, the extent of the contribution has not yet been sufficiently studied.

Table 9.1 Summary of the final assessment of the risks for final impact on people and final risk for the economy.

Topic	**Impact**	
	People	*Economy*
Heat (Heat-related mortality and burden of disease)	High (>100,000 persons affected and >100 deaths)	No statement
Heat (Temperature-related mortality)	High (>100 deaths per year)	
Air quality	High (>100,000 persons affected and >100 deaths)	High (> €1 billion)
Mental health	High (>100,000 persons affected)	Medium (€100 million–€1 billion)
UV radiation	High (>100,000 persons affected and >100 deaths per year)	Medium (€100 million–€1 billion)
Pollen allergies	High (>100,000 persons affected)	Medium (€100 million–€1 billion)
Infectious diseases (mosquitos)	Low (<10,000 persons affected)	Low (< €100 million per year)
Infectious diseases (Lyme)	Medium (10,000–100,000 persons affected)	
Infectious diseases (tick-borne Encephalitis)	Low (<10,000 persons affected)	
*Infectious diseases (*Vibrio*)*	No statement	
Infectious diseases (waterborne)	Low (<10,000 persons affected)	
*Infectious diseases (*Legionella*)*	Medium (10–100 deaths)	

The final risk for the economy varies and is often estimated. For heat, no research has yet been done in the Netherlands to be able to make any statement on this. Air quality, as an environmental health topic, already has quite an impact on the economy. The contribution of climate change has not yet been sufficiently researched, but the costs are large anyway. For mental health, UV radiation and pollen allergies, the final risk is estimated at medium, partly because the magnitude of the contribution of climate change over the past 30 years cannot always be determined. For the infectious diseases studied, the final risk to the economy is low.

Not all people are equally affected. For each topic, there are different groups that are particularly vulnerable to the health effects of climate change.

There are still many knowledge gaps for all topics. This already makes estimating some current health effects difficult and estimating the effect of climate change even more difficult. This report therefore also highlights the recommendation to develop more knowledge on the health effects of climate change.

To start researching the actual impact of climate change on health, it is important to properly monitor the aforementioned indicators and possibly develop new ones. Additional focus should be placed on developing more knowledge on the cumulative effects that can occur in conditions involving heat, air pollution and pollen at the same time.

The potential negative health effects in terms of pollen allergies and infectious diseases should also be taken into account when taking adaptation measures.

The fact sheets serve as a prelude to the next phase when future health effects due to climate change will be determined.

Main report references

ANV (2022a). Leidraad risicobeoordeling Rijksbrede Risicoanalyse Nationale Veiligheid, Analistennetwerk Nationale Veiligheid.

Corvalán, C., Kjellstrom, T., Smith K.R. (1999). Health, environment and sustainable development: identifying links and indicators to promote action', Epidemiology, 10: 656–60.

Hall, E.F., R.J.M. Maas, J. Limaheluw, C.D. Betgen (2021). Mondiaal klimaatbeleid: gezondheidswinst in Nederland bij minder klimaatverandering. RIVM-Rapport 2020-0200.

Hambling, T., Weinstein, P., Slaney, D. (2011). A review of frameworks for developing environmental health indicators for climate change and health. Int J Environ Res Public Health 8:2854–2875

Huynen, M., Vliet, A. van, Staatsen, B., Hall, L., Zwartkruis, J., Kruize, H., Betgen, C., Verboom, J. en Martens, P. (2019). Kennisagenda klimaat en gezondheid. ZonMw.

Kelfkens, G., P. Ruyssenaars, J. van der Ree (2021). Klimaatakkoord: Gevolgen van het uitfaseren van fossiele energie voor veiligheid, gezondheid en stikstofdepositie; een update. RIVM-rapport 2020-0143.

KNMI (2021). Klimaatsignaal '21. Hoe het klimaat in Nederland snel verandert, KNMI, De Bilt, 72 pp.

Leerdam, R.C. van, J.H. Rook, L. Riemer, N.G.F.M. van der Aa (2023). Waterbeschikbaarheid voor de bereiding van drinkwater tot 2030 – knelpunten en oplossingsrichtingen. RIVM-rapport 2023-0005.

Morris, G.P., Beck, S.A., Hanlon, P., Robertson, R. (2006). Getting strategic about the environment and health. Public health. 2006 Oct 31;120(10):889-903

PBL (2015). Wereldwijde klimaateffecten: risico's en kansen voor Nederland, Den Haag.

Van der Ree, J., E. Honig, P.A.M. Uijt De Haag, G. Kelfkens, M.F. van de Ven (2019). Klimaatakkoord: effecten op veiligheid, gezondheid en natuur. RIVM-rapport 2019-0076.

Van der Ree, J., C. Betgen, C. Boomsma, A. van Dijk, L. Hall, D. Houweling, J. Limaheluw, K. Rijs (2022). Plan van aanpak Onderzoeksprogramma Klimaatverandering en gezondheidseffecten. RIVM-rapport 2022-0030.

Witmer, M.C.H. et al. (2023), Nationale klimaatrisicoanalyse 2022 – 2026; Uitwerking analysemethodiek. Den Haag: Planbureau voor de Leefomgeving.

World Health Organization, (2004). Environment and Health Indicators for Europe: a pilot indicator-based report. World Health Organization Regional Office for Europe; 2004

Wuijts, S., A.C. Vros, F.M. Schets, M.A.H. Braks (2014). Effecten van klimaat op gezondheid: Actualisatie voor de Nationale Adaptatiestrategie (2016). RIVM-rapport 2014-0044.

Appendix 1 Uncertainty and reliability classification

The following terminology is used in the fact sheets when it comes to uncertainty and reliability (Witmer et al., 2023).

Uncertainty term	**Probability (percent)**	**Probability (fraction)**
Virtually certain	More than 99% probability that an outcome/conclusion is true	≥ 99 in 100
Very likely	90–99% probability that …	≥ 9 in 10 and ≤ 99 in 100
Likely	66–90% probability that …	≥ 2 in 3 and ≤ 9 in 10
Medium likelihood	33–66% probability that …	between 1 and 2 in 3
Unlikely	10–33% probability that …	≤ 1 in 3 and ≥ 1 in 10
Very unlikely	1–10% probability that …	≤ 1 in 10 and ≥ 1 in 100
Exceptionally unlikely	Less than 1% probability that ...	≤ 1 in 100

Reliability class	**Description**
Very high	- a lot of information available, all or almost all parts completed based on data, models, observations, etc.; - outcome(s) based on reliable methods, techniques and analyses; - little or no spread in outcomes of studies and experts (high consensus); - no or few uncertainties that have no impact on outcomes.
High	- a lot of information available, many parts completed based on data, models, observations, etc.; - little spread in outcomes of studies and experts; - few uncertainties that have no significant impact on outcomes.
Average	- a sufficient amount of information available, varied based on data, models, observations etc. and expert assessment; - limited spread in outcomes of studies and experts; - limited uncertainties that have a limited impact on outcomes.

Reliability class	**Description**
Low	- a limited amount of information available, only a few parts completed based on data, models, observations, etc.; - moderate spread in outcomes of studies and experts; - presence of uncertainties that may have an impact on outcomes.
Very low	- no or hardly any information available, all parts completed using expert assessment; - large spread in outcomes (low consensus); - major uncertainties that may have a major impact on outcomes.

Appendix 2 Climate resilience of the healthcare sector in the event of extreme weather

PBL asked RIVM to briefly review what information is known about the climate resilience of the healthcare sector in the event of extreme weather. A number of relevant reports found are described here. This is a small selection and not the result of a comprehensive literature review.

Extreme weather situations such as prolonged drought and heat, floods from the river or sea, extreme precipitation, downbursts and storms occur in the Netherlands. Climate change may intensify extremes, and they will occur more frequently (KNMI, 2021). These types of extreme weather events can cause damage and, in some cases, social disruption. The National Network of Safety and Security Analysts (*Analistennetwerk Nationale Veiligheid*, ANV) has developed a thematic report on climate and natural disasters for this purpose. This report describes the impacts on the Netherlands in the event of extreme climate-related and nature-related disasters (ANV, 2022b).

In the case of casualties, the healthcare sector is called upon during or after extreme weather. The healthcare sector needs to prepare for climate change by strengthening the climate resilience of the healthcare system itself and of related essential services (Huynen et al, 2020). Climate change threatens the quality and continuity of healthcare. Extreme weather events can lead to emergencies with challenges such as increases in patient numbers, damage to infrastructure, facilities such as electricity or water or waste disposal that cease to function and disruption of supplies (Huynen et al, 2020).

During prolonged heat, the National Heatwave Plan[107] ensures that hospitals are informed of prolonged heat and are thus prepared for a possible extra influx of patients. Also, patients who are hospitalised can be subjected to extra monitoring.

TNO (2015) examined the water resilience of Dutch hospitals. Floods and extreme precipitation can directly threaten buildings, including hospitals. This study shows, among other things, that many emergency services are located on the ground floor and that emergency power facilities are mostly located in the basement or on the ground floor. This leaves hospitals vulnerable to flooding and may jeopardise the delivery of healthcare. The Meander Medical Centre in Amersfoort is an example of a water-robust hospital with vital functions 2.6 metres above sea level.

Appendix 2 references

ANV (2022b). Themarapportage klimaat- en natuurrampen, Analistennetwerk Nationale Veiligheid.

[107] https://www.rivm.nl/en/heat/national-heatwave-plan

Huynen, M., Vliet, A. van, Staatsen, B., Hall, L., Zwartkruis, J., Kruize, H., Betgen, C., Verboom, J. en Martens, P. (2019). Kennisagenda klimaat en gezondheid. ZonMw.

KNMI (2021). Klimaatsignaal ’21. Hoe het klimaat in Nederland snel verandert, KNMI, De Bilt, 72 pp.

TNO (2015). Waterrobuustheid Nederlandse ziekenhuizen. TNO 2015 R11234

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