IVM Institute for Environmental Studies

Impacts of Climate Change on Public Health on Bonaire

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Summary

Climate change is the biggest “global health threat facing humanity” in the 21st century. Climate change will very likely affect public health on Caribbean small islands, as small island developing states are highly vulnerable to the climate change impacts on health. Currently, small island developing states already “carry heavy burdens” in the form of non-communicable diseases, malnutrition, and obesity. The Caribbean region is especially vulnerable to the impacts of climate change and this project investigates the impacts of climate change on Bonaire’s public health situation.

The effects of climate change on various aspects of Bonairians’ health conditions are determined by focussing on the impacts on vector-borne diseases, non-communicable diseases, and mental health, among others. In order to explore the current health situation on Bonaire and the possible impacts on public health associated with climate change, desk research is combined with expert interviews.

Although climate change induced floods can result in increased injury and accidental mortality (WHO, 2021), such physical trauma only makes up a minor part of the health climate change impacts. In reality, many more impacts can be seen in terms of vector-borne diseases, non-communicable diseases, mental health, and other health problems. The results indicate that Bonaire’s public health is vulnerable to climate change affecting vector-borne diseases, malnutrition and food insecurity, non-communicable diseases, heat-related stress and mortality, and mental health issues, among others. Decision-makers should take their responsibility to support Bonaire’s adaptation to the expected impacts accordingly.

1 Introduction

Climate change (CC) is the defining concern of our time (UN, n.d.). Small islands are disproportionately affected by climate change, especially considering their minor contribution to global greenhouse gas emissions (IPCC, 2021; PAHO, 2019). Small islands are particularly vulnerable because of their small economies and often low-lying, large coastal areas which foster their lifestyles (Carabine & Dupar, 2014; Macpherson & Akpinar-Elci, 2013). The Intergovernmental Panel on Climate Change (IPCC) (2022) is confident that small islands will suffer from temperature increases, changes in precipitation patterns, sea level rise (SLR), coral bleaching, and extreme weather events, such as tropical cyclones, droughts, and storms, as a result of climate change.

Climate change will also disproportionately affect the Caribbean small island region (Nurse *et al*., 2014). Small island states in the Caribbean and their inhabitants are already being affected, through SLR and weather changes, and indirect climate change effects, such as impacted fisheries and reduced food security (Alliance of Small Island States, 2009). The IPCC predicts higher temperatures, less precipitation, and SLR in the future (Akpinar-Elci & Sealy, 2014; Nurse *et al*., 2014). These projected changes will produce environmental, economic, and social damage and put further pressure on the small islands (Akpinar-Elci & Sealy, 2014; Dutch Caribbean Nature Alliance, 2019).

To minimise the pressures associated with climate change, the impacts need to be managed with care (Dutch Caribbean Nature Alliance, 2019). However, non-economic loss and damage (NELD) from climate change, including negative impacts on public health, is often overlooked because non-economic impacts are difficult to quantify and are often not noticed by the wider society (Serdeczny *et al*., 2016). Research on Caribbean islands mostly overlooks climate change NELD, as many studies investigate the climate change impacts on tourism demand, the economy, and nature (Akpinar-Elci & Sealy, 2014; Moore, 2010; Toba, 2009; Wilson, 2017).

However, climate change is the biggest “global health threat facing humanity” in the 21st century, with an estimated additional 250,000 global deaths between 2030 and 2050 (PAHO, n.d.b; WHO, 2008, p.2). Climate change will very likely affect public health on Caribbean small islands, as small island developing states (SIDS) are highly vulnerable to the climate change impacts on health (Rise *et al*., 2022; WHO, 2021a). Currently, SIDS already “carry heavy burdens” in the form of non-communicable diseases (NCDs), malnutrition, and obesity (WHO, 2021a, p.6). Climate change can impact the SIDS’ already vulnerable health situations, directly as a result of SLR, heat waves, droughts, and storms, and indirectly in the form of vector-borne and chronic diseases, malnutrition and food insecurity, and mental health issues (Clayton, 2020; PAHO, n.d.b; PAHO, 2019; Sealy, 2018).

However, literature on NELD associated with health issues induced by climate change in SIDS is relatively scarce. Only 1.4% of studies in a WHO (2021) meta-analysis on climate change and health were dedicated to health in SIDS, even though SIDS are the most vulnerable to the climate change impacts on health (WHO, 2021a). Research on the climate change impacts on health in the Caribbean is also limited, especially at national levels (Rise *et al*., 2022; WHO, 2021a). Even though some health profiles for Caribbean

SIDS exist, there is none for Bonaire (WHO, 2021a), highlighting the need to investigate the climate change impacts on public health on Bonaire.

The goal of this study is to explore how climate change is predicted to impact Bonairian public health. First, this study explores the current Bonairian public health situation. Second, it analyses how Bonairian public health will be affected by climate change by means of literature review and expert interviews

2 Literature review

2.1 Study site

Bonaire is a small island (288 km2) located in the Caribbean Sea, 80 km north off the coast of Venezuela, and has been a public entity within the Netherlands since the Netherlands Antilles dissolved in 2010. Bonaire's terrain is predominantly low-lying and covered by low thorny vegetation (Uyarra et al., 2005).

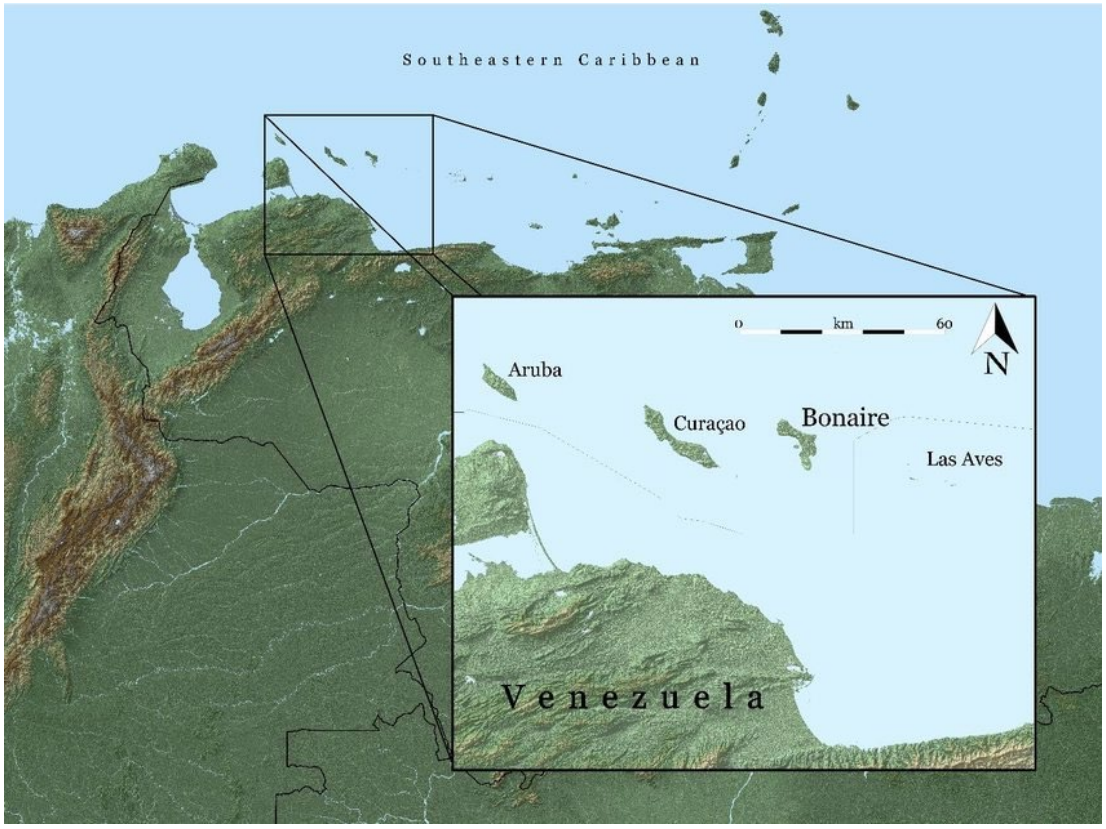

Figure 1 The ABC islands (Antczak, 2019, p.14)

Between 2010 and 2022, the population of Bonaire has grown from 15,500 to 22,600 people (CBS, 2022). This growth was mainly attributable to migration and is expected to continue (CBS, 2022). The population is diverse, with residents from the Caribbean Netherlands, Southern, Central, and North America, and the European Netherlands. Figure 2 shows the population by region of birth as of 1 January 2021.

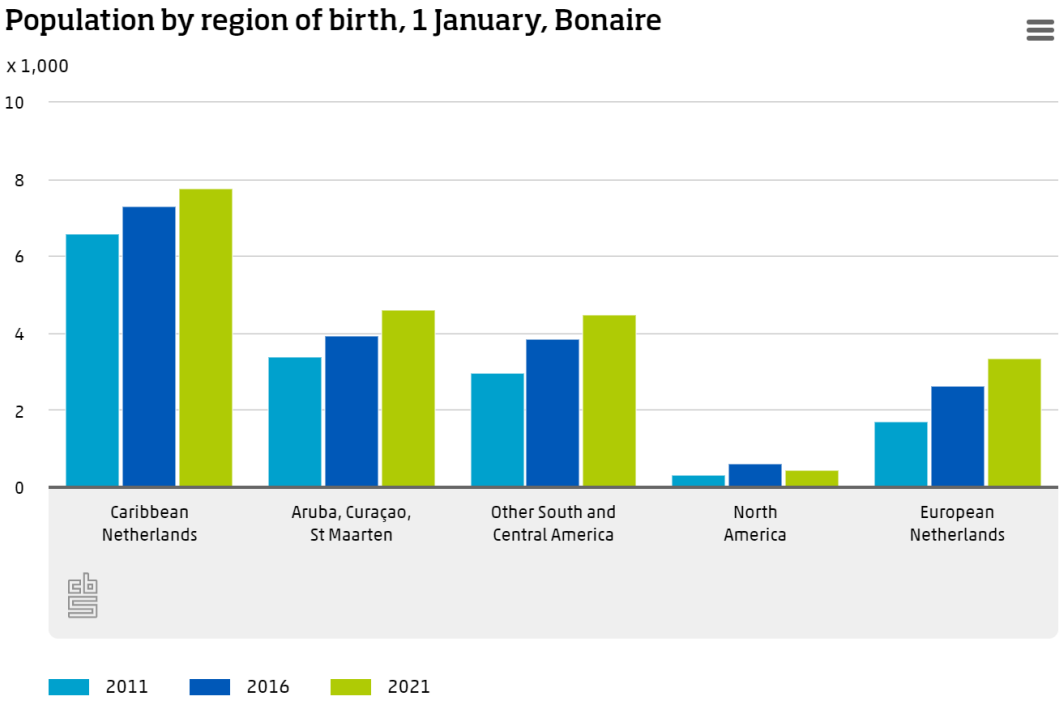

Figure 2 Bonaire population by region of birth (Statistics Netherlands, 2021)

Bonaire exhibits a semi-arid steppe, but also tropical climate with alternating wet and dry seasons ranging from October to January and February to May respectively. As Bonaire is located in the Southern Caribbean Dry Zone, its climate is drier compared to the rest of the Caribbean (Meteorological Department Curaçao, n.d.; Verweij *et al*., 2021). The tropical climate exhibits small temperature differences between seasons with seasonal mean temperatures between 26℃ and 29℃ (Meteorological Department Curaçao, n.d.; Schmutz *et al*., 2017). The fairly constant temperatures and distinct wet and dry seasons are presented in figure 3.

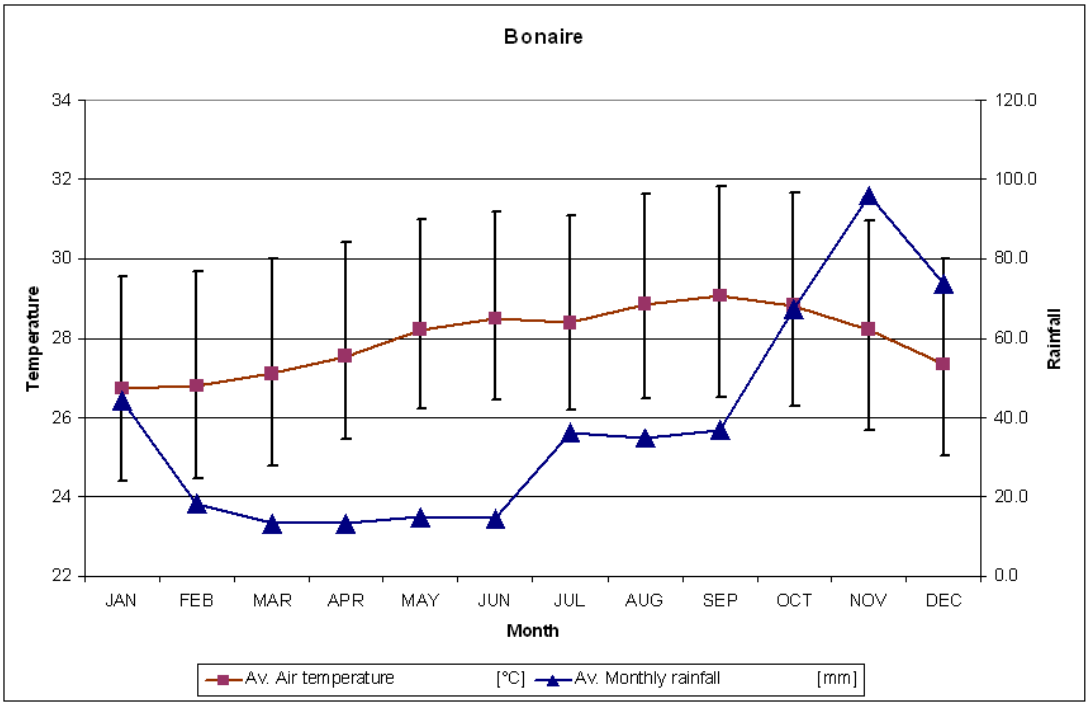

Figure 3 Climate summary for Bonaire (Meteorological Department Curaçao, n.d.)

2.2 Climate change on Bonaire

This section summarizes the physical changes that are expected to occur in Bonaire's climate as a result of climate change. More detailed information is presented in the study from Dullaart & van Manen (2022) and in Annex A.

2.2.1 Temperature

In the Caribbean, extreme temperatures are already occurring at an increased frequency due to climate change (Taylor *et al*., 2020; Stephenson *et al*., 2014). Due to the lack of a multi-year time series of temperature on Bonaire, no trends in temperature change can be assessed with island specific data (Dullaart & van Manen, 2022). However, on Curaçao, Bonaire's neighbouring island, mean temperature has increased by 0.6℃ since 1980 (KNMI, 2021). Furthermore, in all IPCC scenarios by 2100, a temperature increase is expected (Taylor *et al*., 2020). This increase is ranging from 0.83℃ to 3.05℃ for the least to most extreme scenario with respect to the baseline period 1986-2005 (Taylor *et al*., 2020).

Table 1 *Physical changes projected for the Caribbean and Bonaire in the different climate change scenarios (Angeles-Malasapina et al., 2018; Taylor et al., 2020; NASA, 2022)*

			2050	2100	2150
		SSP1/RCP1.9	NA	NA	
	Projected **mean temperature** increase (°C) with respect to 1986-2005 (Caribbean) * shows the range of the projections (Taylor *et al.*, 2020)	**SSP1/RCP2.6**	**0.86°C** *0.39 - 1.57°C	**0.83°C** *-0.04 - 1.74°C	
		SSP3/RCP6.0	**1.00°C** *0.69 - 1.66°C	**1.85°C** *1.00 - 2.92°C	
		SSP5/RCP8.5	**1.50°C** *0.94 - 2.23	**3.05°C** *2.10 - 4.22°C	
		SSP1/RCP1.9	NA	NA	
	Projected mean **precipitation** change (%) with respect to 1986-2005 (Caribbean)	**SSP1/RCP2.6**	-0.09	-0.46	
		SSP3/RCP6.0	-2.42	-6.91	
		SSP5/RCP8.5	-6.27	-16.95	
		SSP1/RCP1.9	0.23	0.47	0.70
	Projected **sea level rise** (m) relative to 1995-2014 (Bonaire)	**SSP1/RCP2.6**	0.24	0.51	0.78
		SSP2/RCP4.5	0.25	0.64	1.05
		SSP5/RCP8.5	0.27	0.85	1.45

2.2.2 Precipitation and sea level rise

As shown in table 1, the Caribbean can expect an increase in temperature, in the frequency of heat waves and SLR, and a decrease in precipitation in all IPCC scenarios (Taylor *et al.*, 2020; NASA, 2022). Currently, there has already been a declining trend in rainfall during the summer months in the Caribbean (IPCC, 2021). However, this trend is not statistically significant at the five percent significance level (Taylor *et al.*, 2020; Jones *et al.*, 2015). In fact, for Bonaire no significant positive or negative trend in precipitation has been observed so far (KNMI, 2021).

The sea level in the Caribbean is rising at a similar rate (1.8mm/year) as the global rate (1.7mm/year) and has risen by 10.6 cm from 1950 to 2009 (Taylor *et al*., 2020; Palanasamy *et al*., 2015; Torres & Tsimplis, 2013). This means that the SLR around Bonaire and the Caribbean is expected to rise slightly faster than on average around the world (KNMI, 2021). According to the IPCC's scenario pathways, the projected range of SLR for 2081-2100 compared to 1986-2005 for the Caribbean region is between 0.47 (SSP1-1.9) and 0.85 (SSP5-8.5) metres rise in sea level (Akpinar-Elci & Sealy, 2014; Nurse *et al*., 2014). Verweij *et al*. (2020) argue that one of the challenges for Bonaire is the adaptation to SLR.

2.2.3 Extreme weather events

Extreme weather events due to climate change are projected to increase in the Caribbean (Hersbach *et al*., 2019; Debrot *et al*., 2018; Verweij *et al*., 2020). Bonaire is threatened by an increasing frequency, duration, and intensity of heat waves, and increased aridity resulting from a higher intensity and frequency of droughts (Hersbach *et al*., 2019; Debrot *et al*., 2018; IPCC, 2021). Tropical cyclones considerably damage Bonaire ca. every 100 years with flooding, and worse storms due to climate change also can also cause damage on Bonaire (Dutch Caribbean Nature Alliance, 2019; Meteorological Service Netherlands Antilles and Aruba, 2010).

2.3 Public health

Public health is concerned with ensuring and improving the health of entire populations. Public health can be targeted at local communities, nations, or regions through researching diseases, preventing and controlling infectious diseases, and promoting a healthy lifestyle (CDC Foundation, n.d.).

2.3.1 Public health on Bonaire

Bonaire's increasing life expectancy has reached 80.2 years in 2017 (Openbaar Lichaam Bonaire, 2020). However, the population is disproportionately suffering from NCDs (HE3). NCDs "tend to be of long duration" (WHO, 2021b, para. 1) and include cardiovascular diseases, chronic respiratory diseases, diabetes, and cancers. NCDs cause 71% of all global deaths and often result in premature deaths 30 to 69 year-olds. With 31% of overweight and 30.4% obese residents, and 47.1% of the population having high blood pressure, Bonaire is increasingly at risk for NCDs (WHO, 2021b). Currently, 8.1% of Bonaire's population suffers from type II diabetes, 6% from asthma, and 4% from cardiovascular diseases in 2017 (Openbaar Lichaam Bonaire, 2020).

Due to its tropical climate, Bonaire is also vulnerable to heat stress and vector-, food-, and water-borne diseases (Akpinar-Elci & Sealy, 2014; WHO, 2020). Vector-borne diseases are infectious diseases caused by parasites, bacteria, or viruses, and are spread by vectors, such as mosquitoes or ticks (WHO, 2020). Bonaire hosts the viral mosquito-borne diseases chikungunya, dengue, and zika (WHO, 2020). Chikungunya causes fever and severe joint pain that can become chronic (PAHO/WHO, n.d.). Dengue is mild and asymptomatic in 80% of the cases, however it can result in flu-like illnesses and develop into severe dengue (WHO, 2022). Zika includes symptoms like fever, conjunctivitis, muscle, and joint pain (WHO, 2018a). A zika infection during pregnancy can lead to

congenital malformations in born infants and neurological complications (WHO, 2018a). So far, there are no cures for these vector-borne diseases and chikungunya and dengue can cause death in case of late detection and improper access to medical care (PAHO/WHO, n.d.; WHO, 2018a; WHO, 2022). In 2016, Bonaire reported 37 cases of chikungunya and 45 cases of dengue (Duijster & Hahné, 2016). Food- and water-borne diseases result from the consumption of food or water that is contaminated through environmental pollution or unsafe food storage or processing (WHO, n.d.). The government's 2020 health report does not report on food- and water-borne diseases on Bonaire, but literature considers diarrheal diseases and leptospirosis relevant food- and water-borne diseases in tropical climates (PAHO, 2019; Sealy, 2018).

There appears to be a scarcity of information about Bonairians' mental health issues. According to UNICEF (n.d.), there is a lack of data on adolescents' knowledge, attitudes, and risky behavior in the Caribbean Netherlands, particularly in the areas of sexual and mental health. This is remarkable given the extent to which the European Netherlands has invested in this type of study aimed at young people.

2.3.2 The impacts of climate change on public health

Climate change affects mental and physical health. Figure 4 shows the interlinkages between climate hazards, health determinants, and health outcomes. Climate hazards are climate-related events usually causing damage, such as property damage, economic loss, or stress on health (Hobbs, 1987). Health determinants describe the context in people's lives that determines their health, including their socio-economic and physical environment, personal characteristics, and behaviours (WHO, 2017a). Health outcomes measure changes in an individual or a group's health situation, where the changes are usually attributed to interventions like treatments (Sedgley, 2013). In this study, we are particularly interested in the changes that can be attributed to climate change and its consequences. Figure 4 shows that climate change affects health directly and indirectly (Hariharan & Zeldin, 2021). This model is a partial exploration of climate change impacts on health and is completed in the results section, which analyses the climate change impacts on physical trauma, vector-borne diseases, NCDs, heat-related stress, malnutrition and food insecurity, water-borne diseases, skin diseases, and mental health.

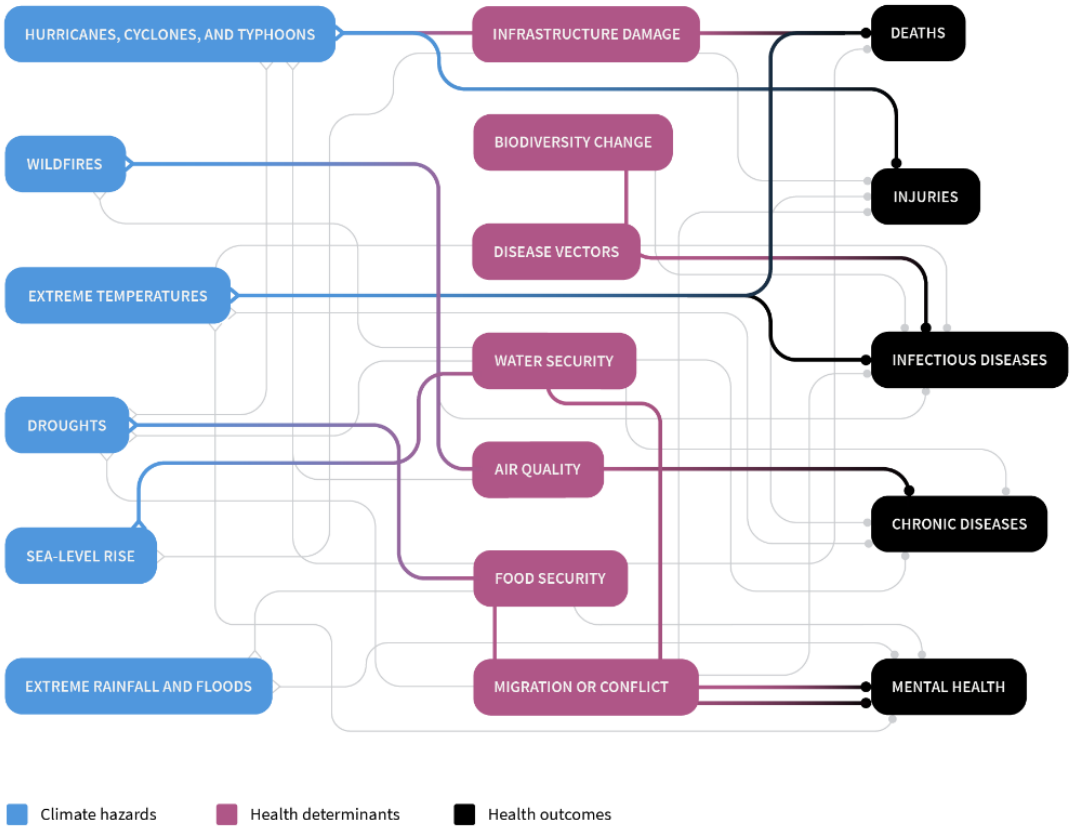

Figure 4 The impacts of climate change on health (Marsh McLennan, n.d.)

3 Methodology

3.1 Desk research

The desk research on public health for the literature review and results relied on different sources, which are presented in table 2.

Table 2 Main sources used during the desk research on public health

Topic	Source(s)
Public health on Bonaire	Openbaar Lichaam Bonaire (2020)
Vector-borne diseases	Duijster & Hahné (2016); PAHO (2020); WHO (2018a); WHO (2020); WHO (2022)
Non-communicable Diseases	Akpinar-Elci & Olayinka (2017); PAHO (2020); WHO (2021b)
Mental health	PAHO (2020); World Bank (2021)
CC impacts on health in the Caribbean	Public health reports, academic papers, WHO reports, PAHO reports

The literature search was performed on Google and Google Scholar. The main search terms included “public health Bonaire” and “impacts of climate change on health (on Bonaire/in the Caribbean)”. After identifying the main threats to health from climate change, the research was specified by looking up the climate change impacts on specific diseases.

3.2 Expert interviews

There is limited knowledge on the climate change impacts on health on Bonaire. Therefore, interviews with health experts were necessary to explore how climate change is predicted to affect health on Bonaire. The interviews also served to determine whether Bonaire already sees climate change impacts on public health and how the island has coped with past extreme events. Relevant experts were found by identifying authors of public health reports and academic articles on climate change and health in the Caribbean, and professionals interviewed for newspaper articles on public health and climate change in the Caribbean. The snowballing technique was used to get in touch with additional experts. After each interview, the experts were asked if they knew other relevant experts. The interviewed experts have knowledge of health (e.g. infectious diseases) and the Caribbean (e.g. from the Caribbean Public Health Agency, CARPHA, and PAHO), but also experts with specific health knowledge to Bonaire were interviewed. In total, seven health experts participated in the research. The list of experts and their functions is attached in Annex B.

This research used semi-structured, in-depth interviews. Using an interview guide ensured that the most important topics were touched upon while allowing for flexibility through probing (Hesse-Biber & Leavy, 2011; Young *et al.*, 2018). The interviews lasting 40 minutes to one hour were performed in April and May 2022. Most interviews took place online. However, the interviews with the experts from Fundashon Mariadal took place at Fundashon Mariadal Bonaire. The interviews were performed in English and at a later stage transcribed using the software otter.ai in a verbatim format.

Lastly, this study did not attempt to quantify the climate change impacts on health. This decision has been taken in response to a statement by PAHO, that “because of the complexity of the processes involved, it is difficult to estimate the magnitude of the possible effects of climate change on health” (PAHO, 2017, p.13). Similarly, HE2 put forward that the impact of climate change on health is ‘only’ “measurable from the fact that we see an increase in illnesses”. Moreover, this study does not take different climate scenarios into account. HE7 explains that despite the belief that there will be additional effects on health when temperatures increase further and that the effects of climate change become more visible. However, the expert emphasises that the differences between the scenarios are highly uncertain, and argues in favour of focusing on the general effects of climate change on health (HE7) as a first exploration.

4 Results

Climate change is already affecting and will continue to affect physical and mental health worldwide (Clayton, 2020; PAHO, 2019; Sealy, 2018). WHO estimates predict about 250,000 additional deaths per year due to heat stress, malnutrition, dengue, and malaria, between 2030 and 2050 (PAHO, n.d.b; Sealy, 2018). Akpinar-Elci and Sealy (2014) point out that climate change impacts can worsen diseases that small, tropical islands like Bonaire are vulnerable to, such as heat stress, asthma, and vector-, food-, and water-borne diseases. Therefore, it is important to explore the possible climate change impacts on health on Bonaire to be able to educate the population and prepare the public health sector.

Note that this section considers heat waves and droughts as separate phenomena because they are highly relevant for the climate change impacts on health on Bonaire. We use the term "extreme weather events" to refer to storms, heavy precipitation, flooding, and tropical cyclones. Although climate change induced floods can result in increased injury and accidental mortality (WHO, 2021), such physical trauma only makes up a minor part of the health climate change impacts. In reality, many more impacts can be seen in terms of vector-borne diseases, NCDs, mental health, and other health problems (PAHO, 2020).

Research has mostly been performed on the climate change impacts on health in the Caribbean region, but not for Bonaire specifically. After consulting multiple health experts, this paper assumes that the research on climate change and health in the Caribbean is transferable to Bonaire (HE6). However, the individual Caribbean islands still experience different climates (HE1; HE6; HE7). Hence, there will be unique differences in the climate experiences of the different countries and islands, which might result in slightly different climate change impacts on health (HE1). Bonaire suffers from a drier climate and is at a lesser risk of extreme weather events such as hurricanes and heavy precipitation events than most Caribbean islands, making it more vulnerable to health issues related to drought and heat waves (HE1; HE6; Meteorological Department Curaçao, n.d.).

4.1 Vector-borne diseases

Figure 5 shows a simplified flowchart of how climate change is expected to affect vector-borne diseases on Bonaire. A variety of socio-economic factors, such as urbanisation and changes in vector control, influence the expansion of vector-borne diseases (Åström *et al*., 2012; WHO, 2022). However, climate change is also likely to influence vector-borne diseases, as it creates a more suitable climate for vector survival (PAHO, 2020; WHO, 2022). Changing climate conditions in countries with endemic dengue have facilitated dengue transmission by 9.5% since 1950 and climate change is expected to increase dengue transmission by 300% (Sealy, 2018).

Climate change is likely to influence vector-borne diseases as it creates a more suitable climate for vector survival (PAHO, 2020; WHO, 2022). Changing climate conditions in countries with endemic dengue have facilitated dengue transmission by almost 10%

since 1950 and climate change is expected to increase dengue transmission by significantly (Sealy, 2018).

A warmer climate, along with increased humidity, speeds up mosquito reproduction and disease transmission risk of dengue for example (PAHO, 2020; Rocklöv & Tozan, 2019). The hotter the climate, the faster the mosquitoes breed, the shorter the diseases' incubation time, and the higher the risk of disease transmission (Akpinar-Elci & Sealy, 2014; HE1; Sealy, 2018; WHO, 2017b). Models predict this to happen with dengue transmission in many tropical regions as temperatures will increase (Åström *et al*., 2012; Iwamura *et al*., 2020). The climate change induced temperature changes could also result in a suitable minimum temperature for malaria transmission in the Caribbean, a region where malaria is not endemic (Nurse *et al*., 2014).

The increased incidence of extreme weather events, such as storms leading to pluvial and coastal flooding, could further increase the exposure of Caribbean SIDS populations to vector-borne diseases (CDC, n.d.). Flooding can "facilitate the stagnation of water, which leads to an increase in breeding sites" (PAHO, 2020, p.54) and temporarily increases mosquito numbers two to three weeks after (HE7) and increases the number of vector-borne diseases (HE1). However, some extreme events, such as heavy precipitation, can destroy the mosquitoes' breeding sites (PAHO, 2020).

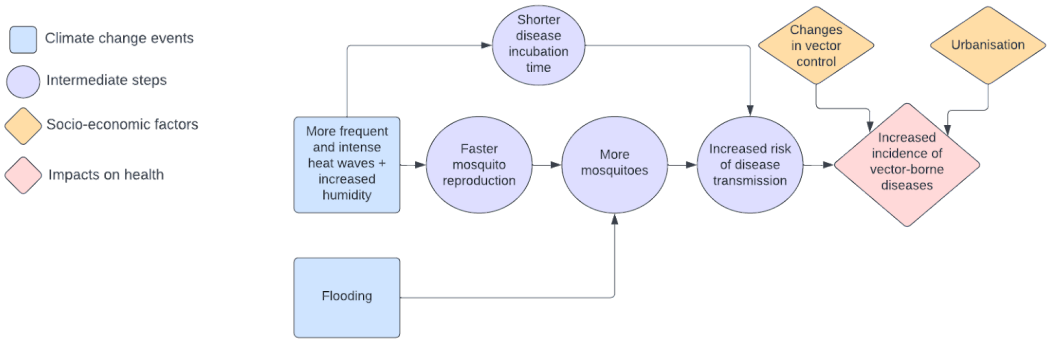

Figure 5 Flowchart showing the simplified impact of climate change on vector-borne diseases

Changes in vector-borne disease incidence in the Caribbean are already seen. HE1 specifies that the mosquito breeding process has already shortened from ten to twelve days to five to seven days. HE2 puts forward that, with the outbreak cycles decreasing from about ten years in the past, vector-borne diseases seem to have accelerated to a year or two now (HE2). Lastly, it has been argued that climate change may have played a role in the emergence of chikungunya in a variety of Latin American and Caribbean countries (Yactayo *et al*., 2016).

Even though most research on the climate change impacts on health in the Caribbean has been performed in terms of vector-borne diseases, HE1 believes that the biggest burden in the future will come from chronic diseases. Whereas vector-borne diseases need a faster response because they appear and disappear at fast paces, an exacerbation in chronic diseases can be expected from time to time with climate change (HE1).

4.2 Non-communicable diseases

Figure 6 shows a simplified flowchart of how climate change is expected to affect NCDs on Bonaire. It is expected that climate change will directly impact non-communicable diseases through increasing temperatures, extreme weather events, and air pollution (PAHO, n.d.b, HE1; HE7). Respiratory, cardiovascular, circulatory, and kidney problems are among the ailments that could be exacerbated (PAHO, n.d.b). Increasing temperatures will aggravate non-communicable diseases by worsening the symptoms felt from these diseases (HE7; HE1; Public Health Department Saba, n.d.). In line with this, PAHO (2020) has determined an increase in cardiovascular diseases as a result of the thermal stress incurred during heat waves, and Liu and colleagues (2015) have found a correlation between heat and cardiovascular disease deaths.

Extreme weather can also cause patients with non-communicable diseases to experience a worsening of their symptoms because “their care may be jeopardised” (HE7). HE3 adds that patients suffering from non-communicable diseases often live in houses that are vulnerable to flooding, which may result in a negative impact on the patients’ access to healthcare during heavy precipitation events. It could be that in such instances the patients lose their housing, do not use their medication in the right way, or get misaligned with their sugar levels (HE3). As such, the climate change impacts on the patients’ health will be exacerbated by their social status. As many Caribbean countries, including Bonaire, already suffer from high incidences of NCDs (HE2; HE4), higher incidences and hospital admissions due to non-communicable diseases are likely to worsen their situation and put even more burden from non-communicable diseases on the hospital services (HE2).

Additionally, climate change’s impact on air quality might exacerbate the impact air pollution already has on human health in the Caribbean (Macpherson & Akpinar-Elci, 2015). More specifically, climate change will change the concentration of respiratory allergens in the air (D'Amato *et al*., 2014). This is partly due to high temperatures (PAHO, 2020) and extreme weather events, such as heavy precipitation and flooding, that foster mould, fungi, and other bioaerosols (Ivey *et al*., 2003). Consequences of this can be an increase in allergic rhinitis, asthma, and respiratory problems (HE3; PAHO, 2020; WHO, 2009). HE3 emphasises that this is especially problematic for people who already have health problems in the form of non-communicable diseases, which are widespread on Bonaire. In line with this, research has already touched upon increased mortality and morbidity due to respiratory problems related to heat (Patz *et al*., 2014).

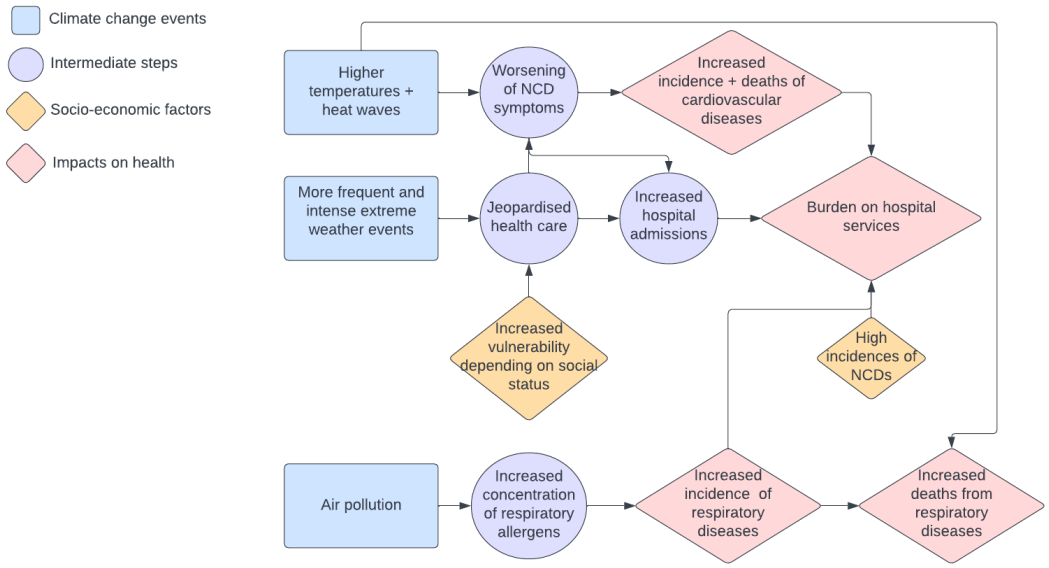

Figure 6 Flowchart showing the simplified impact of climate change on NCDs

Changes in non-communicable diseases in the Caribbean can already be seen. HE2 puts forward that CARPHA is seeing a higher incidence of non-communicable diseases because they are affected by climate change. HE1 confirms that differences are being seen on the chronic disease side and that this has an effect on the whole Caribbean.

4.3 Heat-related stress

Figure 7 shows a simplified flowchart of how climate change is expected to affect heat-related stress on Bonaire. An increase in temperature caused by climate change makes Bonairians more susceptible to heat-stress disorders. Although specific data on changes in daytime and night-time temperatures for Bonaire are unavailable, projections indicate an upward trend for both warm days and nights in the Caribbean as a whole. Cool days, on the other hand, are predicted to decrease. The predicted range of very warm days and nights for the Caribbean region is broad. For example, predictions range between 51 and 251 warm days and 24 and 360 warm nights by the end of the century for RCP 8.5 (The Caribbean Development Bank, 2020).

There are definite and absolute limits to how much heat exposure an individual can tolerate. More frequent and intense heat waves can have a direct effect on health through an expected increase in heat-related illnesses, such as the most commonly found heat-related exhaustion and heat stress, but also heat strokes and heat-related mortality (HE1; Health Canada, 2011; PAHO, n.d.b; WHO, 2021). Death rates have been shown to increase during heat waves and deaths due to heat mostly come from heat stroke but can also be related to cardiovascular diseases (Akpinar-Elci & Sealy, 2014; CDC, 2020; Sealy, 2018). Vulnerable populations, such as the elderly and people with severe obesity, as well as people with underlying conditions are especially susceptible to disorders and mortality from heatwaves. This is relevant for Bonaire, whose proportion of obese inhabitants (more than 30%) is relatively high compared to Northern Europe (RIVM, 2017; Openbaar Lichaam Bonaire, 2020). In addition, from 2019 to 2030, the percentage of individuals older than 65 years is projected to increase

from 13% to 19% (CBS, 2019), and hence increasing the vulnerability of the Bonarian population to heat-related disorders and mortality. Kovats and Hajat (2007) explain that “risk factors can also be categorised as intrinsic (age, disability) and extrinsic (housing, behaviours); the latter vary according to location and adaptations to the local climate.” The extrinsic risk factors suggest that differences in vulnerability exist between people from different social classes, since not all people may have the means to adapt their housing conditions to protect themselves from heat exposure.

Heat-related stress can also occur as a result of an extreme weather event, i.e. hurricane, when people lose access to fans and air conditioning (CDC, n.d.). HE7 assumes that with a faster increase in temperatures heat stress may be exacerbated more. Poorer people on Bonaire may be disproportionately hit by heat-related stress for their bodies, as they do not have the financial means to keep their homes at bearable temperatures (HE3).

HE5 adds that higher temperatures prevent people from moving as they prefer to stay inside (HE7), and that the current Bonairian hot climate from July to October are likely to already have negative impacts on health, although it has never been quantified (HE4).

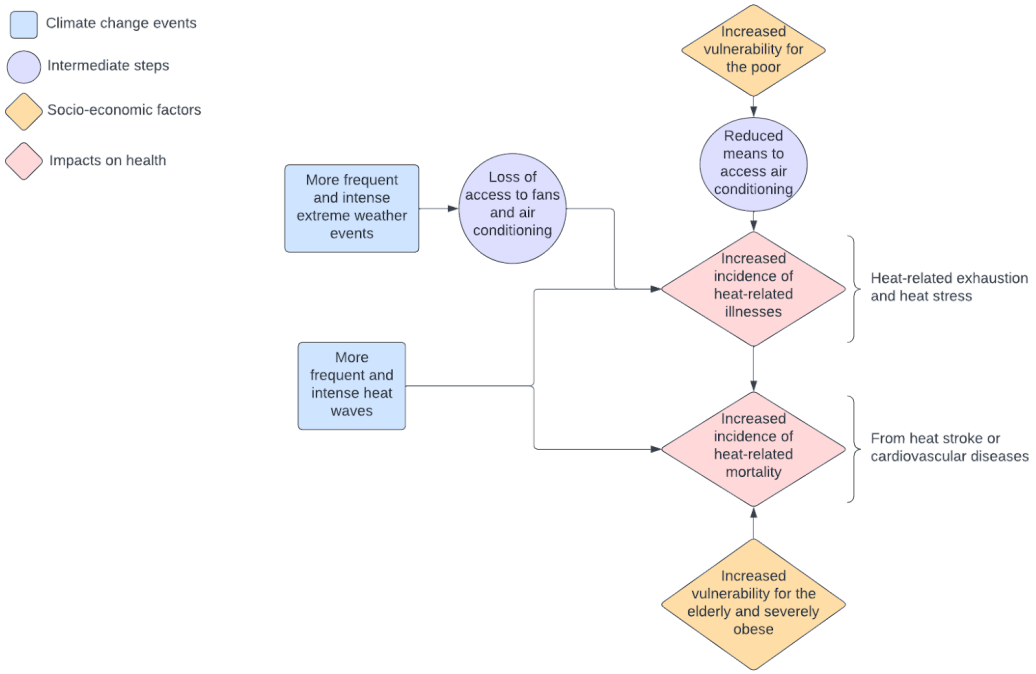

Figure 7 Flowchart showing the simplified impact of climate change on heat-related stress

4.4 Malnutrition and food security

Figure 8 shows a simplified flowchart of how climate change is expected to affect undernutrition and food insecurity on Bonaire.

Climate change is expected to affect undernutrition on Bonaire, which is a deficiency of nutrients, and food insecurity. Climate change can lead to indirect impacts through socio-economic systems in the form of undernutrition and food security problems

(PAHO, n.d.b; WHO, 2021). Bonaire is currently 99% dependent on imported food (Verweij *et al*., 2020). HE4 confirms that Bonaire does not produce its own fruits and vegetables, and that Bonairians only keep a small number of goats and chicken for consumption. Climate change with its consequent changes in temperature, drought events, ocean warming, and ocean acidification is likely to cause a reduction in crop, livestock, or fisheries yield, thereby posing strong risks to food availability and causing further increases in the cost of healthy food (IPCC, 2022). As a result, undernutrition could occur. Furthermore, rising temperatures and limited budgets already lead to trade-offs having to be made between, for example, spending money on nutritious food for healthy nutrition intake and electricity for air conditioning to protect against heat-related disorders. (HE3). Rising prices and temperature changes could exacerbate these trade-offs, indicating that the socioeconomic status of Bonairian residents could impact their susceptibility to the health effects of climate change. PAHO (n.d.b) finds that there could even be combined effects from the increased incidence of infectious diseases and undernutrition. Additionally, undernutrition can have an even more extreme effect on children, through the chronic effects of stunting and wasting (PAHO, n.d.b).

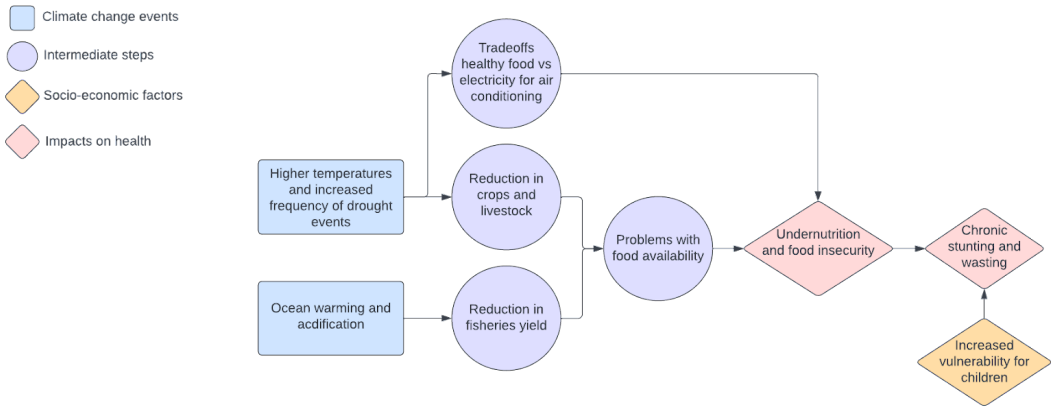

Figure 8 Flowchart showing the simplified impact of climate change on undernutrition and food insecurity

Extreme weather events are not necessarily seen as a threat to food security on Bonaire, because the Netherlands will assure emergency supplies, as was provided by the Royal Netherlands Navy for St. Maarten after hurricane Irma (CE4). HE4 also agrees that events like pandemics will likely not lead to food insecurity on Bonaire. During COVID-19, the shipping industry was seen as essential and did not experience any troubles (World Bank, 2021). However, the World Bank (2021) has found that COVID-19 affected food prices on Bonaire, which could result in unhealthier eating and associated health consequences.

4.5 Water and humidity-related diseases

Climate change can have an indirect effect on water-borne diseases and other water-related health impacts mostly due to increased exposure of the population to pathogens (WHO, 2021; PAHO, n.d.b). Heavy rainfall on Bonaire sometimes leads to high water standing in the neighbourhoods. As such, heavy rainfall and floods can

pollute drinking water with pathogens, fostering water-borne diseases such as diarrheal diseases, gastroenteritis, and leptospirosis (HE7; PAHO, 2020; Sealy, 2018; WHO, 2017b).

Climate change can also have a negative impact on skin diseases. Due to heat-related humidity, the skin can be damaged and become infected (PAHO, 2020). Even though it is not known whether this is related to climate change, the WHO (2019) has found 549 new cases of skin melanoma in the Caribbean in 2018.

4.6 Mental health

Figure 9 shows a simplified flowchart of how climate change is expected to affect mental health on Bonaire. Climate change is expected to affect mental health on Bonaire. People with existing mental health problems are part of one of the groups within society that are most vulnerable to the negative consequences of climate change (Patz *et al*., 2014; PAHO, 2020). Additionally, climate change can lead to newly developing mental illness and stress in multiple ways (HE4; PAHO, n.d.b; WHO, 2021). The impact of climate change on mental health is important, as the mental health consequences can affect individuals, or even whole families, for months to years (The Climate Institute, 2011).

Extreme weather events that are related to climate change, such as floods, drought, and hurricanes can lead to mental health issues appearing before, during, or after their occurrence (PAHO, 2020). HE1 also puts forward that impacts on mental health can be seen in the aftermath of extreme weather events such as storms and hurricanes, as these come with psychological trauma for the survivors who may have had to leave their homes and had to live in shelters (CDC, n.d.; HE4). Research shows that more than half of adults suffer from depression after natural disasters and that 30 to 40% of extreme weather event survivors, especially from flooding (Alderman *et al*., 2012), suffer from post-traumatic stress (Akpinar-Elci & Sealy, 2014; Goldmann & Galea, 2014; Sealy, 2018). Moreover, heat waves can lead to an increased number of hospital admissions due to mental health problems (Khalaj *et al*., 2010), mostly because people with mental health issues find it difficult to adapt to very high temperatures (Vida *et al*., 2012). Other psychosocial problems that can result from extreme weather events are alcoholism and drug abuse (Silove *et al*., 2006). Furthermore, during extreme weather events or pandemics, the burden of psychosocial problems in the population may increase, for example, as a result of lost employment and/or (property) damages (PAHO, 2020).

Climate change potentially increases the risk of pandemics (FAO, 2005), which also drastically affect physical and mental health. With COVID-19, the number of mental health patients on Bonaire has increased from 159 clients in 2019 to 286 clients in 2020 (World Bank, 2021). Extreme weather events and pandemics can also impact the mental health of health professionals and reduce their ability to deliver adequate healthcare (HE7). Accordingly, HE7 emphasises the importance of mental health training for health professionals. Moreover, participatory mapping shows that Bonairian residents strongly value nature and link it to their cultural identity. As a result, when the ocean and its coral reefs are degraded through climate change, their positive contribution to public mental health on Bonaire will be greatly diminished (World Bank, 2020).

Figure 10-1 shows a simplified flowchart of how climate change is expected to affect public health on Bonaire, which is based on information from expert interviews and literature review. However, impacts on health are complex and cannot directly be quantified.

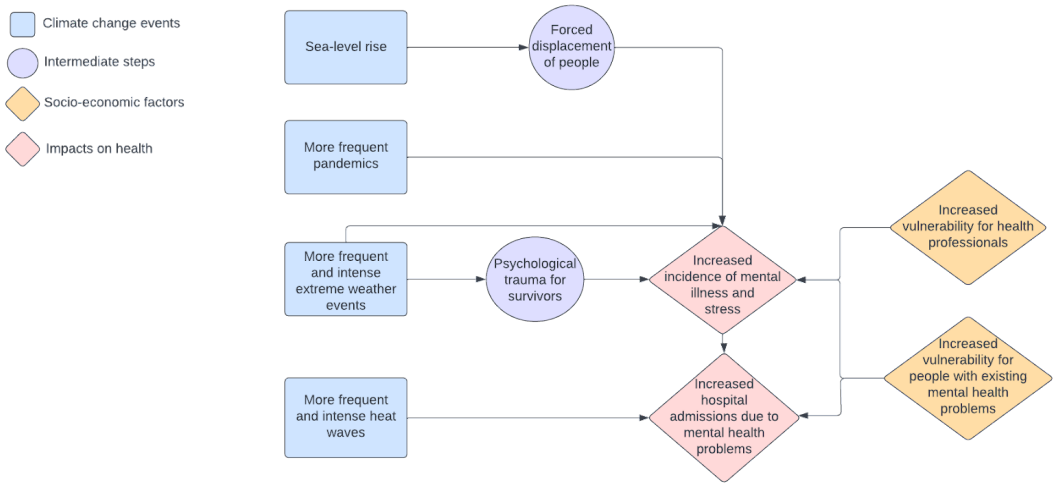

Figure 9 Flowchart showing the simplified impact of climate change on mental health

Climate change can also result in the forced relocation of people or migration due to SLR (Simpson, 2010). For Bonaire, staying with the current emissions trajectory would mean that by 2050 the island would already have to displace part of its population and infrastructure (Sealy, 2018), as SLR will threaten Bonaire's South and potentially Kralendijk (Dullaart & van Manen, 2022). Forced displacement of the population due to climate change can have health consequences in terms of increased appearance of mental health disorders and threats to wellbeing (PAHO, 2020; Thomas & Benjamin, 2018).

4.7 Critical infrastructure

HE4 sees serious risks from climate change for Bonaire and its population's health as the island only has one hospital, water fabric, energy supplier, and airport, all located in coastal areas. Figure 10 shows Bonaire's hospital. Even though Bonaire's hospital has plans to move away from the coast within 15 years (HE4), it is still relevant to examine what could be the climate change consequences for public health during these years.

Critical infrastructure in low-lying areas is vulnerable to SLR and extreme weather events (CDC, n.d.), in times of which much-needed "health service delivery and healthcare access" may be jeopardized due to damages to the infrastructure and to essential equipment (PAHO, 2019). Extreme weather events can cause power shortages or situations where the medical services cannot function (CDC, n.d.). Even though Bonaire is less at risk of hurricanes, it can suffer from the effects of accompanying storm surges and stronger winds (HE5). On a positive note, Bonaire's hospital is currently approved for category three plus hurricanes (HE5). Heat waves can also impair the proper functioning of hospitals if they are not prepared to operate (WHO, 2017b).

Figure 10 Bonaire's hospital San Francisco in Kralendijk (ABC Online Media, n.d.)

Additionally, Bonaire's desalination and electricity plants are located in critical locations close to the shore (CE3; HE4). According to CE3 and HE4, SLR and the risk of hurricanes, storms, and consequent flooding seriously threatens these plants that are essential for human life on Bonaire. This is in line with Simpson's (2010) statement that SLR can damage infrastructure and the CDC's (n.d.) findings that such climate change impacts can pose a threat to easily accessible safe water supplies, which may affect health. HE4 specified that there are plans to move the desalination plant to a higher altitude within the coming 15 years.

4.8 Uncertainties concerning the impacts of climate change on health

The climate change impacts on health are complex and cannot be quantified. Accordingly, one can classify the uncertainty of different climate change impacts on health based on the uncertainty of the climate change explanatory factors that are at play. Table 3 shows the uncertainties related to the climate change explanatory factors that are related to health impacts. The IPCC uses five levels of confidence, very high, high, medium, low, and very low, which are defined according to the evidence and scientific agreement, as shown in figure 11 (Australian Government, n.d.).

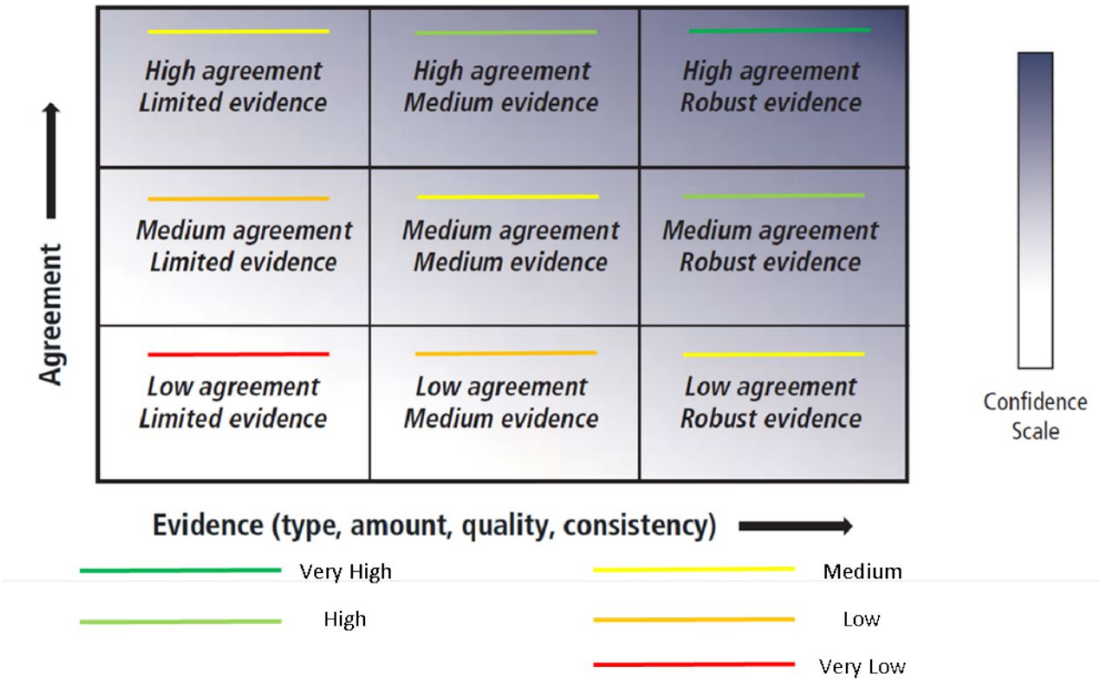

Figure 11 Confidence scale of the IPCC (Australian Government, n.d.)

Table 3 Confidence related to the impacts of climate change on health (IPCC, n.d.)

Impact on health	Climate change explanatory factor	Confidence of climate change explanatory factor increase
Vector-borne diseases	Temperature increase and heat waves	High
	Floods (precipitation and storms)	High
	Temperature increase	High
NCDs	Extreme weather events	High (coastal flood)
		Medium (tropical cyclone)
	Air pollution	High (atmospheric CO2 at surface)
Heat-related stress	Heat waves	High
	Extreme weather events (e.g. tropical cyclone)	Medium
Malnutrition and food insecurity	Heat waves	High
	(Agricultural) drought	Medium
	Ocean warming and acidification	High
Water-borne diseases	Floods	High
Mental health	Floods	High
	Droughts	Medium
	Tropical cyclones	Medium

5 Discussion

5.1 Implications of the results

Because the literature on climate change impacts on Bonairian health is limited, the implications of the results can only be discussed to a limited extent. This research's results confirm Hariharan and Zeldin's (2021) findings that climate change affects physical and mental health directly and indirectly. The experts mentioned most climate hazards and health determinants from Marsh McLennan's (n.d.) framework. The experts and literature review also considered the impact of climate change on skin diseases, a health outcome that was not included in Marsh McLennan's (n.d.) framework.

5.2 Limitations and recommendations for further research

The WHO (2021c) describes a common limitation of analysing the climate change impacts on health: "Although it is unequivocal that climate change affects human health, it remains challenging to accurately estimate the scale and impact of many climate-sensitive health risks." Thus, this study did not attempt to quantify the climate change impacts on health and emphasised the uncertainty underlying climate change and its possible impacts on human health. In addition, the implications of climate change on health in the different climate change scenarios could not be analysed, since the scenarios would likely produce subtle differences in the impacts of climate change on health, while the magnitude of those nuances are not yet understood. In addition to looking into the impact of climate change on health in different scenarios, more research should be conducted on the health impacts from climate change that are rarely discussed in the literature, such as "climate-related dietary changes", air pollution, heat waves, and mental health stress (WHO, 2021, p.25). More data should be collected on the incidence of these health issues on Bonaire so that long-term trends can be identified and possibly linked to climate change.

Because there is not enough research on the predicted climate change impacts on health on Bonaire, this study had to assume that the information on the climate change impacts on health in the Caribbean is also applicable to Bonaire. Thus, the findings offered are mostly not specific to Bonaire but apply to the Caribbean region in general. Additionally, even though the health experts that were interviewed include three employees from Fundashon Mariadal, it was impossible to get in touch the Openbaar Lichaam Bonaire (OLB) to discuss climate change and health data specific to Bonaire. Moreover, the health experts from CARPHA were not allowed to provide country-specific data on Bonaire without permission, which limited the results section to data from the Caribbean region. Currently limited information is available on the evolution of health and disease risks on Bonaire (HE4). Preferably, the RIVM and OLB should collect public health data more regularly, preferably annually instead of every four years. This could help identify health trends related and unrelated to climate change in 20 to 30 years (HE4).

5.3 Policy recommendations

Even though the results are uncertain and assumptions have been made, policy recommendations are valuable to allow Bonaire to protect itself and its inhabitants against the climate change impacts on health and culture. These recommendations stem mostly from the experts, who have comprehensive knowledge of Bonaire.

To mitigate climate change impacts on health, all essential infrastructure, including healthcare facilities, schools, police and fire stations should rely on smart infrastructure (HE6). Such infrastructure includes safety measures and a more environmentally friendly consumption. Bonaire's health infrastructure should be remodelled together with the European Dutch government based on the climate change physical impacts predicted for Bonaire, so that healthcare can be kept up to a maximum during natural disasters (HE3).

The climate change health impacts, such as an increase in vector-borne diseases, also represent a threat to the social and economic development of Bonaire (Nurse, 2020). Accordingly, it is important to maximally prevent vector-borne diseases, through protective measures, surveillance systems, and community education (WHO, 2020).

6 Conclusion

Figure 13 shows a summary of the predicted climate change impacts on Bonairian public health. With increasing awareness of climate change and its possibly disastrous consequences in the Caribbean, it is essential to analyse how climate change is predicted to impact the vulnerable Caribbean SIDS, such as Bonaire. In the public health domain, climate change is very likely to negatively affect vector-borne diseases, NCDs, heat-related stress, food insecurity, mental health, and health infrastructure on Bonaire. Even though a quantification of the predicted effects is impossible, the literature and experts agree that climate change will negatively affect health on Bonaire.

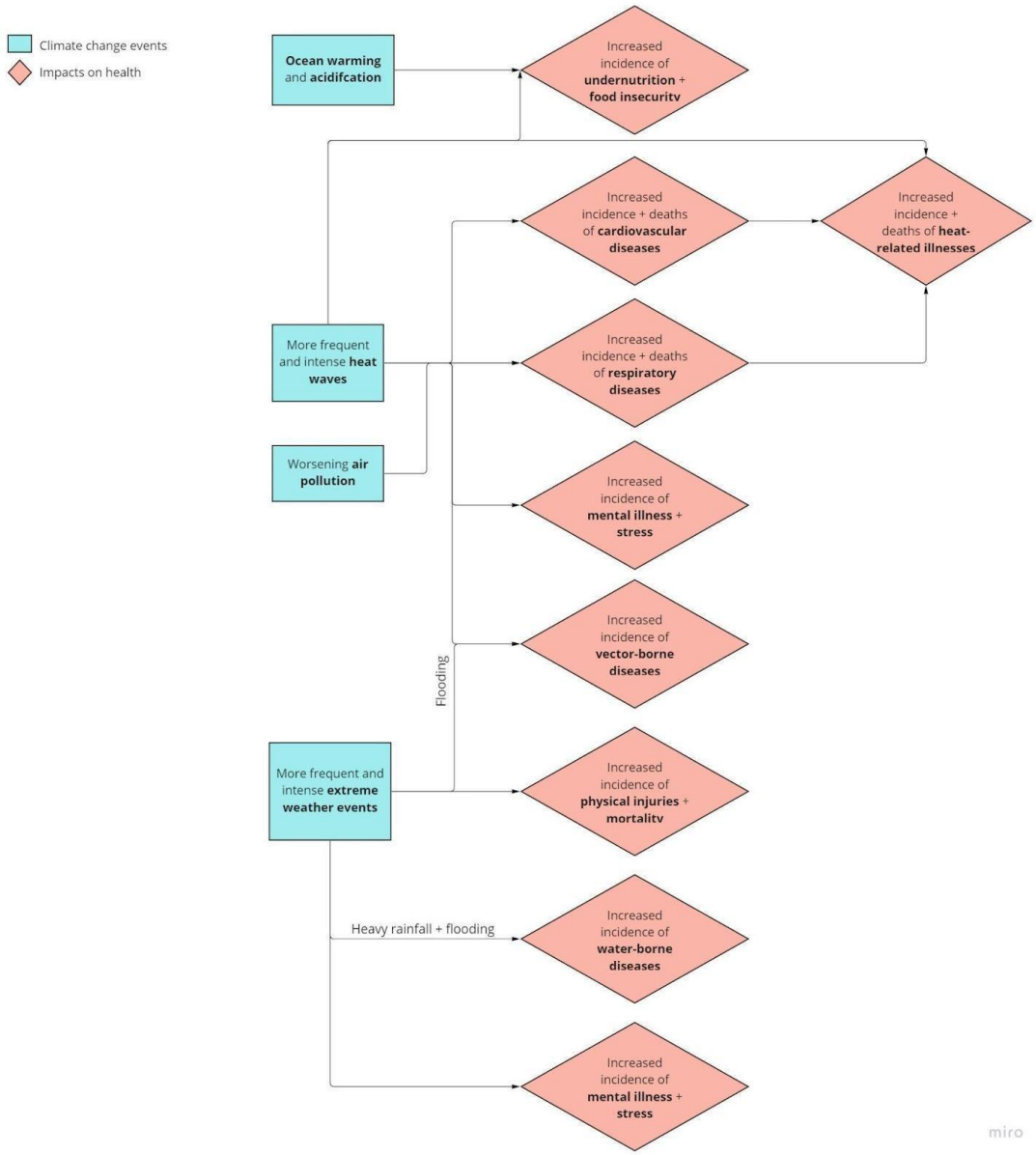

Figure 13 Potential impacts of climate change on Bonairian public health

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UNICEF Nederland (2019). *Situatieanalyse kinderen en jongeren in Caribisch Nederland*

Annex A The impacts of climate change on Bonaire

Temperature

In the Caribbean, extreme temperatures are already occurring at an increased frequency (Taylor *et al*., 2020; Stephenson *et al*., 2014). However, no multi-year temperature time series is available for Bonaire (Dullaart & van Manen, 2022). On Curaçao, Bonaire's neighbouring island, mean temperature has increased by 0.6℃ since 1980 (KNMI, 2021). According to the IPCC's intermediate low pathway (RCP4.5), the projected change in temperature for 2081-2100 compared to 1986-2005 for the Caribbean region is a 1.4℃ increase in temperature (Akpinar-Elci & Sealy, 2014; Nurse *et al*., 2014). More specifically, in all IPCC scenarios a temperature increase is expected (Taylor *et al*., 2020).

Precipitation

Currently, there has already been a declining trend in rainfall during the summer months in the Caribbean (IPCC, 2021). However, this trend is not statistically significant at the five percent significance level (Taylor *et al*., 2020; Jones *et al*., 2015). On Bonaire specifically however, no positive or negative trend in precipitation has been seen so far (KNMI, 2021). Figure A1 shows annual anomalies in temperature and precipitation on Bonaire from 1979 to 2019.

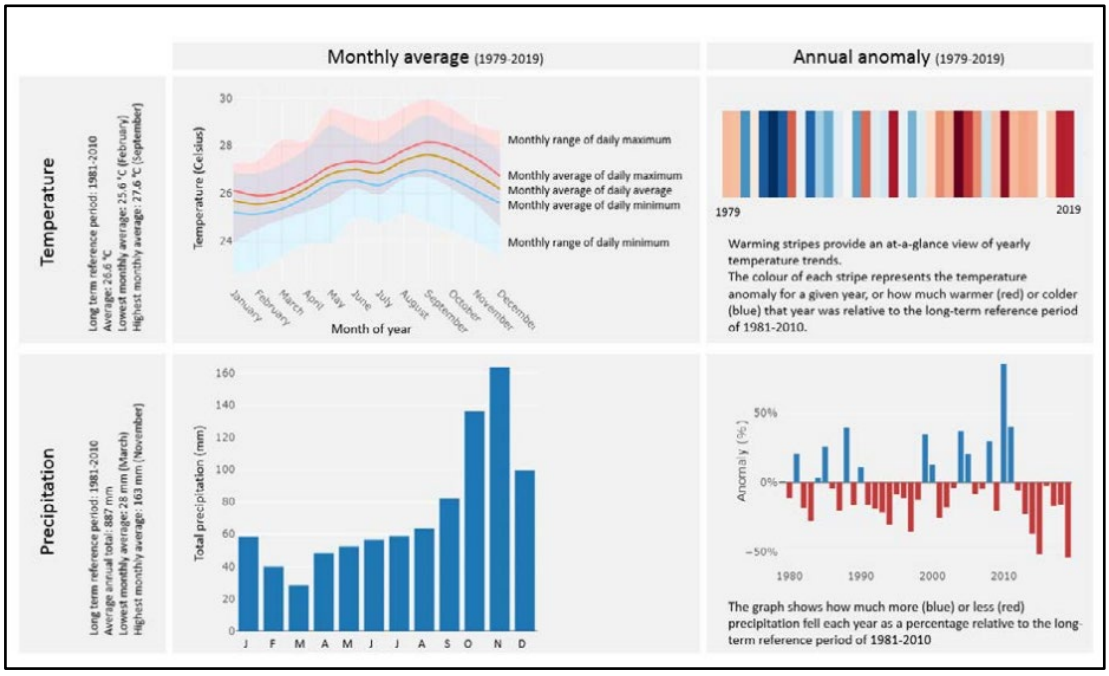

Figure A1 Bonairian average climate and annual anomalies from 1979 to 2019 (Hersbach et al., 2019)

According to the IPCC's intermediate low pathway (RCP4.5), the projected change in precipitation for 2081-2100 compared to 1986-2005 for the Caribbean region is a 5% decrease in precipitation (Akpinar-Elci & Sealy, 2014; Nurse *et al*., 2014). More

specifically, in all IPCC scenarios a precipitation decrease is expected (Taylor *et al*., 2020).

Sea level rise

The sea level in the Caribbean is rising at a similar rate (1.8mm/year) than the global rate (1.7mm/year) and has risen by 10.6 cm from 1950 to 2009 (Taylor *et al*., 2020; Palanasamy *et al*., 2015; Torres & Tsimplis, 2013). This means that the SLR around Bonaire and the Caribbean is expected to rise slightly faster than on average around the world (KNMI, 2021). According to the IPCC's intermediate low pathway (RCP4.5), the projected SLR for 2081-2100 compared to 1986-2005 for the Caribbean region is a 0.5 to 0.6 metres rise in sea level (Akpinar-Elci & Sealy, 2014; Nurse *et al*., 2014). Verweij *et al*. (2020) argue that one of the challenges for Bonaire is the adaptation to SLR.

Extreme weather events

Heat waves and drought

climate change has increased the frequency, duration, and intensity of "warm and hot days and nights" in the Caribbean between 1961 and 2010 (Taylor *et al*., 2020, p.99). Climate change predictions project increased aridity and a higher frequency and intensity of agricultural and ecological droughts across most of the Caribbean (Hersbach *et al*., 2019; Debrot *et al*., 2018; IPCC, 2021).

Tropical cyclones

The IPCC has expressed low confidence in a global increase in tropical cyclone frequency and intensity (Stephenson & Jones, 2017). Bonaire lies on the Atlantic hurricane belt's southern border and experiences tropical cyclones at a much lower frequency than the Dutch Windward Islands (Meteorological Department Curaçao, n.d.). Historically, the ABC-islands are considerably damaged by hurricanes about every 100 years, due to heavy rains and rough seas that can cause flooding for several days (Meteorological Service Netherlands Antilles and Aruba, 2010).

Storms

Storms are predicted to worsen with climate change. Stronger storms, in combination with Bonaire's coral reef degradation, can likely trigger an increase in storm-related damages on Bonaire (Dutch Caribbean Nature Alliance, 2019). Additionally, flooding is expected to increase in frequency and intensity in the Caribbean (CDC, n.d.). Inundation maps for Bonaire in 2150 in the scenarios SSP1-2.6, SSP2-4.5, SSP5-8.5, and SSP8.5 Low Confidence are found in Dullaart & van Manen (2022).

Annex B Lists of experts interviewed and list of participatory mapping

Table B1 List of health experts that were interviewed

Organisation	Department/Function	Expert	Referred to as
CARPHA	Head of Vector Borne Diseases	CARPHA representative	HE1
	Executive director	Dr. Joy St John	HE2
Fundashon Mariadal	Unitleider Technische Beheers Organisatie (TBO)	Felix Greving	HE3
	Advisor to the board of directors	Hans Sauer	HE4
	Operations manager	Burney el Hage	HE5
PAHO	Planning and operations advisor Smart Health Care Facilities in the Caribbean project; Member of Power Health Emergency unit for the Caribbean	Clemens Buter	HE6
/	/	Health expert	HE7