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August 2021

Malaria and Dengue: Understanding two infectious diseases affecting developing countries and their link to climate change

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SOUTH CENTRE

RESEARCH PAPER

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AUGUST 2021

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NOTE

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ABSTRACT

Developing countries will face more complex challenges as infectious disease patterns transform due to climate change and climate variability. These challenges include how to reduce the incidence of malaria (including the significant challenge of resistant malaria), dengue, and other vector-borne and water-borne diseases that are likely to experience alterations in geographical range and lengthening of the transmission seasons due to changing temperatures and rain patterns. Climate extremes, e.g., heat and floods, are implicating the spread of climate-sensitive infectious diseases such as dengue and malaria transmitted by vectors like mosquitoes. In the context of growing financial pressure on governments due to COVID-19, the ensuing fiscal challenges may severely limit the capacity to effectively respond to health challenges in countries already affected by malaria and dengue. Other countries that have made gains in controlling vector-borne infections could also be vulnerable to rising disease burden. This research paper aims to analyze how changes in malaria and dengue pose a challenge for developing countries as they prepare mitigation and adaptation strategies for climate health. The paper will also provide some general recommendations on the importance of integration of health in national climate change strategies.

Les pays en développement devront faire face à des défis plus complexes à mesure que les schémas des maladies infectieuses se transforment en les derniers développements dans la réalisation des droits des paysans dans le cadre de l'UNDROP, et quelles mesures sont nécessaires pour promouvoir sa mise en œuvre en raison du changement et de la variabilité climatiques. Ces défis comprennent la manière de réduire l'incidence du paludisme (y compris le défi important du paludisme résistant), de la dengue, ainsi que d'autres maladies à transmission vectorielle et hydrique susceptibles de subir des altérations de l'aire de répartition géographique et un allongement des saisons de transmission en raison de l'évolution des températures et des précipitations. Les extrêmes climatiques, par exemple la chaleur et les inondations, impliquent la propagation de maladies infectieuses sensibles au climat telles que la dengue et le paludisme transmises par des vecteurs comme les moustiques. Dans le contexte de pression financière croissante sur les gouvernements en raison de Covid-19, les défis budgétaires qui en découlent peuvent sérieusement limiter la capacité à répondre efficacement aux défis sanitaires dans les pays déjà touchés par le paludisme et la dengue. D'autres pays qui ont fait des progrès dans la lutte contre les infections à transmission vectorielle pourraient également être vulnérables à l'augmentation de la charge de morbidité. Ce document de recherche vise à analyser comment les changements dans le paludisme et la dengue constituent un défi pour les pays en développement alors qu'ils préparent des stratégies d'atténuation et d'adaptation pour la santé climatique. Le document apporte également quelques recommandations générales sur l'importance de l'intégration de la santé dans les stratégies nationales de lutte contre le changement climatique.

Los países en desarrollo enfrentarán desafíos más complejos a medida que los patrones de enfermedades infecciosas se transformen debido al cambio climático y la variabilidad climática. Estos desafíos incluyen cómo reducir la incidencia de la malaria (incluido el desafío significativo de la malaria resistente), el dengue, así como otras enfermedades transmitidas por vectores y por el agua que probablemente experimenten alteraciones en el rango geográfico y el alargamiento de las estaciones de transmisión debido a cambios en la temperatura y las precipitaciones. Los extremos climáticos, como el calor y las inundaciones, están implicando la propagación de enfermedades infecciosas sensibles al clima, como el dengue y la malaria, transmitidas por vectores como los mosquitos. En medio de la creciente presión financiera sobre los gobiernos debido al Covid-19, los desafíos fiscales posteriores pueden limitar gravemente la capacidad de responder de manera efectiva a los desafíos de salud en países que ya están afectados por la malaria y el dengue. Otros países que han

logrado avances en el control de las infecciones transmitidas por vectores también pueden ser vulnerables al aumento de la carga de morbilidad. Este documento de investigación tiene como objetivo analizar cómo los cambios en la malaria y el dengue están desafiando a los países en desarrollo mientras preparan estrategias de mitigación y adaptación para la salud climática. El documento también brinda algunas recomendaciones generales sobre la importancia de integrar la salud en las estrategias nacionales de cambio climático.

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1. INTRODUCTION

Science has shown that the climate is changing and that this change is already affecting all life on earth, including humans and the various health and ecosystem systems critical for health and well-being. The significant uptake in greenhouse gas emissions in the last 150 years through human activity has resulted in global warming at an unprecedented pace. In each of the previous three decades, the earth's surface temperature was warmer than any of the preceding decades since 1850 (IPCC, 2014). According to the latest Lancet report, "5 years ago, countries committed to limit global warming to "well below 2°C" as part of the landmark Paris Agreement. 5 years on, global carbon dioxide (CO2) emissions continue to rise steadily, with no convincing or sustained abatement, resulting in a rise in the global average temperature of 1.2°C. Indeed, the five hottest years on record have occurred since 2015" (Watts *et al.*, 2021, p. 1).

Therefore, the implications of this human-induced climate change and the continuing consequences of inaction result in climate variability experienced in different ways across regions and within sub-regions and countries. Shifting weather patterns, extreme heat, rising sea levels, and disasters have intensified in frequency and scale (IPCC, 2014). The consequences of global warming can be seen in immediate risks to lives, for example, when extreme cyclones make landfall, as it was the case in 2020 when tropical cyclone Harold hit the small island state of Vanuatu with a wind speed of more than 250km/h leaving dozens dead in its wake (McGarry, 2020). But the impacts of climate change also have implications for health, including mental health, respiratory diseases and vector-borne diseases. Moreover, temperature changes, fluctuations in rain patterns, and other climate change characteristics are affecting ecosystems and biodiversity. Humans depend on natural ecosystems for survival. Water, food and fuel sources are critical, and the disruptions and alterations of ecosystems make people more vulnerable to the impacts of climate change.

While COVID-19 has emerged as the defining health crisis of 2020 and there has been a welcomed mobilization of action and resources, action on climate change is also urgently needed and should not be left behind in the face of COVID-19. Moreover, there is increasing evidence that climate change may exacerbate the risk of other pandemics due to loss of biodiversity, increased intensive agriculture and temperature changes (Adepoju, 2020; Goodell, 2020). Furthermore, extreme weather events are in some cases overlapping with the COVID-19 pandemic already negatively affecting millions of lives, particularly in developing countries and across vulnerable segments of societies leaving in its trail vulnerable populations and weakened and stressed public health systems.

Climate change, understood as extreme events, as gradual changes or part of slow onset events (sea level rise, increasing temperatures, ocean acidification, glacial retreat, salinization, land and forest degradation, loss of biodiversity, and desertification), has a broad set of implications on humans and ecosystems' well-being. While all life on earth is affected by the changing climate, the impacts are felt differently across populations, with some more prone to be negatively affected. This is particularly the case for people living in Small Island Developing States (SIDS), coastal regions, megacities, mountainous and polar regions. Also, women, men and children who lack or have inadequate access to health services, particularly in developing countries, are at high risk. The World Health Organization (WHO) predicts that between 2030 and 2050, climate change will result in an additional 250,000 deaths per year caused primarily by malnutrition, malaria, diarrhea and heat stress and result in billions of additional health-related costs each year (WHO, 2018). Therefore, analyzing the burden and changes of vector-borne diseases such as malaria and dengue provides a way to illustrate specific impacts of climate change in the health sector. Moreover,

this relationship can help provide a good case study to analyze the importance of integrating health into climate strategies as well as making the case to include climate change into health strategies for developing countries.

However, developing countries have contributed less to climate change as compared to developed countries. Yet, they are at the forefront of the devastating impacts on ecosystems and human lives and are the least resourced to face the increased burden that will be imposed on the health sector. A report from the WHO, The International Research Institute for Climate and Society, The Health and Climate Foundation, and the World Meteorological Organization (WMO) in early 2000 already stressed that: “climate-related health impacts are especially pronounced in poor populations primarily in developing countries, where vulnerable people lack the basic infrastructure to cope with climate variability and change. In these countries, the livelihoods of millions of people are heavily dependent on rain-fed agriculture and seasonal water resources. These communities also bear the greatest burden of infectious diseases” (Guillemot, Adebola and Platzer, 2011, p. 36). Therefore, equipping and supporting health care systems in developing countries is of utmost importance in the years and decades to come.

The relationship between climate change and health is becoming even more critical and has been highlighted in main publications such as the *Lancet Countdown* on health and climate change, the Intergovernmental Panel for Climate Change (IPCC) and WHO reports. The evidence on the effects of climate change on human health is still growing, and even though there is a need to increase knowledge in this area, there is a scientific consensus on the link between the two. Increasingly, policy-makers are proactively seeking to address the intersection between the two from an evidence-based framework. Therefore, there is a need for more case studies and frameworks that explore how to better integrate health-related concerns into climate policy, including its financing.

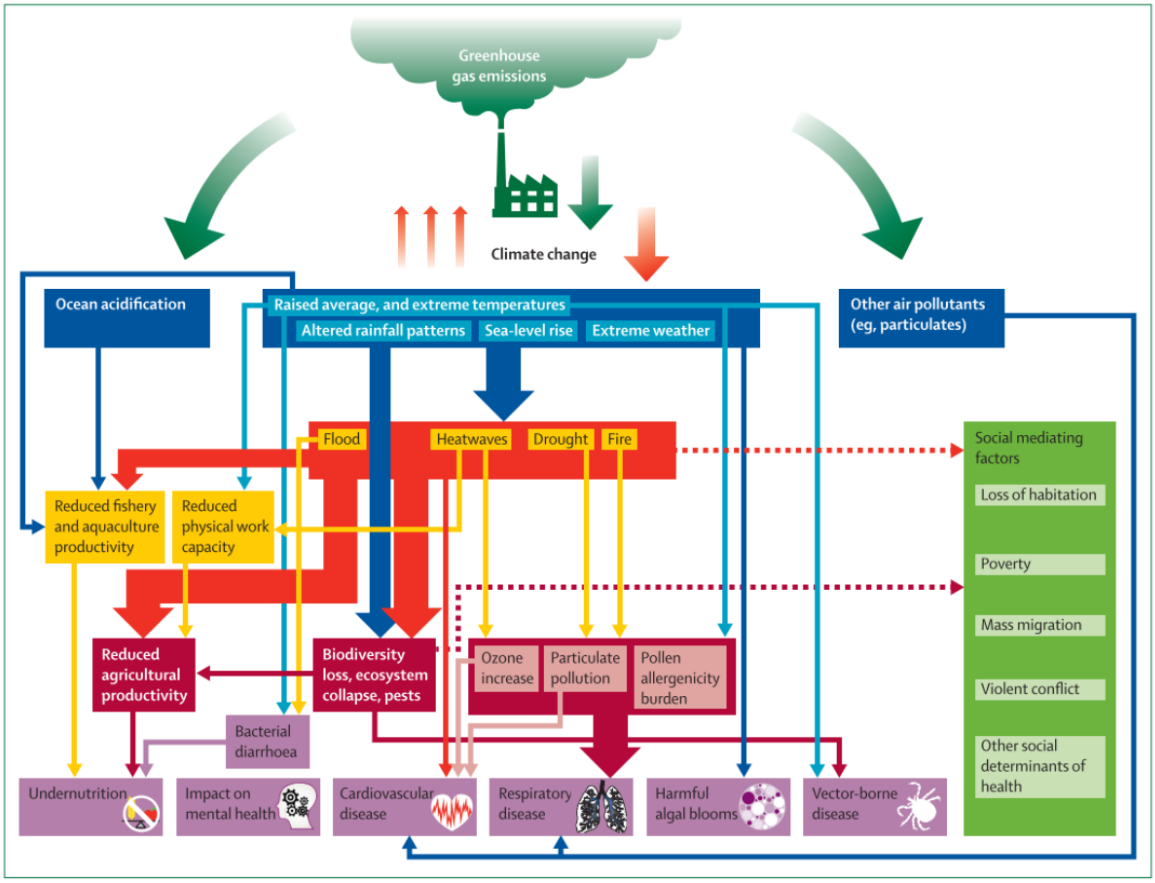
This paper will first provide a brief overview of the general impacts of climate change on health, then explore changes in infectious diseases, specifically malaria and dengue. It will then look into some of the responses to the health impacts of climate change including brief information on existing policy frameworks and global initiatives as well as some examples of addressing health in National Adaptation Plans. It will then provide policy recommendations to highlight some of the impacts of climate change on the health sector particularly for developing countries.

2. Impacts of Climate Change on Health

There are many ways climate change will impact health outcomes. The direct impact on morbidity and mortality will be most visible during and after extreme weather events (Watts *et al.*, 2015). There are also indirect effects such as damages to health infrastructure, including health centers and hospitals. These damages will impact the ability to provide specific health services because of possible damages to infrastructure (Confalonieri, Menezes and de Souza, 2015). Moreover, other areas that will also impact health outcomes include changes in land use, food production and nutrition.

In its publication on climate change and health, the Lancet Commission has provided a diagram to show how different aspects of climate change will affect the health sector, including in the distribution and burden of vector-borne diseases.

Figure 1: An overview of the links between greenhouse gas emissions, climate change, and health



Source: (Watts *et al.*, 2015)

As Figure 1 illustrates, there are many areas where climate change will impact health, including issues of nutrition, mental health, respiratory diseases and vector-borne diseases.

Robust health systems are an essential factor in countries' ability to absorb crises, including changes in infectious diseases and non-communicable diseases and other ongoing problems such as antimicrobial resistance and the COVID-19 pandemic. Because climate change will affect health, its impact on health will need to be considered in climate change adaptation responses; otherwise, this will worsen health problems and result in countries' inability to

face these health challenges. Furthermore, the health sector and current efforts to strengthen primary health care should emphasize the linkages between health and climate. Primary health is generally the first point of contact in providing health services; therefore, equipping and ensuring that plans to strengthen this sector include adapting to better respond to climate change challenges are critical. In many instances, however, national health plans are not considering the effects of climate change and its direct impacts (Kadandale *et al.*, 2020).

Moreover, in developing countries, the health systems already face many vulnerabilities, including lack of appropriate surveillance systems, early warning systems and challenges related to access to treatments, vaccines, and diagnostics (Bardosh *et al.*, 2017)

One of the challenges that health systems will have to face, in the context of climate change, will be its ability to adapt to new risks and, in many cases, to be able to expand its capacity rapidly and effectively to respond. As we have seen with the ongoing COVID-19 pandemic, health systems' ability to provide care in the face of an unknown illness has been overwhelmed in many countries. Robust health systems that can respond to emergencies, outbreaks and new health risks will be critical in the face of climate change.

Health systems are only one part of the response to health risks and in the particular case of infectious diseases, communities and individuals would also need to be prepared to the new patterns, distribution and incidence as well as risk factors of infection and on how to address them (Confalonieri, Menezes and de Souza, 2015). Health systems will need to be prepared to face epidemics and to mitigate threats. Preparations in this regard should include understanding and tracking the biological causes of disease, the nature of transmissions, and the health systems' needs to respond to different emergencies (Fouque and Reeder, 2019).

Examining the current burden of infectious diseases and what changes there will be due to climate change are vital areas that will need to be considered as countries adapt to climate change. Developing countries will need to pay greater attention to infectious diseases and the increasing burden on national health systems. As disease patterns shift, developing countries will be the most affected (Kadandale *et al.*, 2020).

According to a recent study, research on climate change and health has increased substantially, but it still lags compared to other sectors such as transportation and energy. The study also found that the areas of "malnutrition, non-communicable diseases and mental health in particular were understudied, (as were impacts in low- and middle-income countries) and recommend[ed] research capacity-building particularly in the global South" (Fox *et al.*, 2019, p. 13). Therefore, more focus on research in the global South is still needed.

The World Health Organization has produced a series of reports on health and climate change that have resulted in Member States adopting a series of resolutions on the area. One of the resolutions in this area acknowledged "that solutions to the health impacts of climate change should be seen as a joint responsibility of all States and that developed countries should assist developing countries in this regard" (World Health Assembly, 2008). The resolution also urged Member States "to develop health measures and integrate them into plans for adaptation to climate change" (World Health Assembly, 2008).

However, until recently, there has been no coherent global approach to support the management of climate risks to health. Climate variability and change has been seen mainly as an environmental rather than a health issue, and there has been very little investment in climate and health connections (WMO, 2014). Therefore, increasing the investment in the interlinkages between these two areas is critical.

3. CLIMATE CHANGE AND VECTOR-BORNE DISEASES

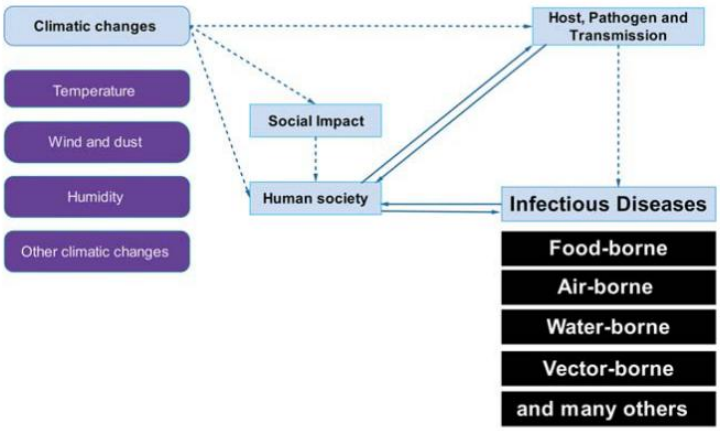
Changes in infectious diseases

The effects of climate change on health encompass many different aspects, including increased stress impacting mental health and extreme heat, which may exacerbate non-communicable diseases. An area of growing concern, particularly in tropical and subtropical areas, is the changes in transmission patterns of vector-borne infection diseases and the high burden that they represent for such countries. It is widely acknowledged that some diseases caused by parasites, viruses, and bacteria are transmitted through vectors, such as mosquitos, flies, and ticks, posing a grave threat to human health (Caminade, McIntyre and Jones, 2019). According to the WHO, vector-borne diseases account for approximately 17% of all infectious diseases (WHO, 2020a).

A recent report by the United Nations Environment Programme (UNEP) has pointed out that "[c]limate change is a major factor in disease emergence. The survival, reproduction, abundance and distribution of pathogens, vectors and hosts can be influenced by climatic parameters affected by climate change. For example, climate variability tends to affect the many diseases transmitted by insects, ticks and other arthropod vectors" (UNEP and International Livestock Research Institute, 2020, p. 17). The report also explains that warmer temperatures would likely influence the incidence of diseases and could increase the vector population. Of these diseases, the mosquito-borne diseases are of particular concern because of the high burden they represent, especially malaria, dengue, chikungunya and Zika (Franklinos *et al.*, 2019). Furthermore, the changes brought about by climate change will likely increase the risk of the emergence of new transmission zones or even re-emergence in areas where it was eradicated (Fouque and Reeder, 2019). Colón-Gonzalez *et al.* explains that "climatic factors such as temperature, precipitation, and humidity modulate many aspects of their biology such as the reproduction rate of the vector and the transmission rate of the pathogens they carry" (Colón-González *et al.*, 2019). Other elements are also linked to how vectors of these diseases may change, including water availability and urbanization and other environmental changes (Bardosh *et al.*, 2017).

The figure below, by El-Sayed and Kamel, illustrates how climatic changes impact the host, the pathogen, the transmission of various infectious diseases and how the hosts and transmission changes will likely generate impacts on human society.

Figure 2: Climatic changes and their impact on pathogens and transmission



Source: (El-Sayed and Kamel, 2020)

It is crucial to emphasize that the highest burden of these infectious diseases, including vector-borne, is highly concentrated in developing countries, specifically in tropical and subtropical areas where significant outbreaks of dengue, malaria and chikungunya, among others, are experienced with more frequency (WHO, 2020a). Two vector-borne diseases of particular global importance are dengue and malaria due to the burden they represent. WHO estimates 3.9 billion people in over 129 countries are at risk of contracting dengue, and that malaria causes approximately 400,000 deaths a year in the African region (WHO, 2020a). Moreover, as explained in the 2014 IPCC report, “these are some of the best-studied diseases associated with climate change, due to their widespread occurrence and sensitivity to climatic factors”(Smith *et al.*, 2014, p. 722). But these are not the only diseases that should be a matter of concern.

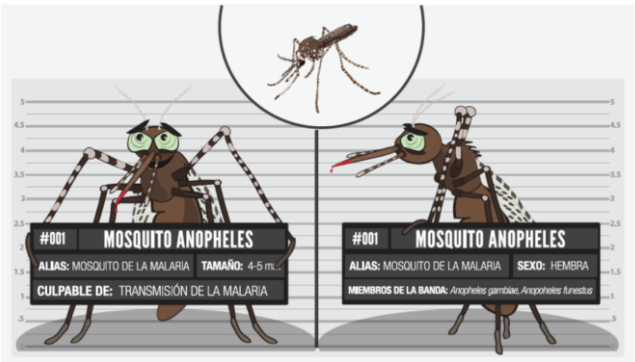
In the case of the mosquitos that transmit dengue and malaria, it has been established that several essential elements determine the mosquitos' ability to survive and develop the pathogens they transmit. Some of the aspects that need to be considered include changes in temperature, rainfall, and humidity (Franklinos *et al.*, 2019). The availability of standing water also plays a key role in the development of the mosquito (El-Sayed and Kamel, 2020). Changes in the land and biodiversity can also affect the vector, including deforestation and soil erosion (Bardosh *et al.*, 2017). All these changes will provoke an effect on the vector and the disease distribution of malaria and dengue (Fouque and Reeder, 2019).

In the case of temperature changes, it is estimated that as temperatures increase, the vectors will move into geographical areas that are cooler in terms of temperature, which could result in expansion to places where it was not previously present (Bardosh *et al.*, 2017). Some of the geographical areas that are likely to see these changes include South America and East Africa’s highland areas.

The case of malaria

Malaria is a disease caused by a parasite (plasmodium falciparum) transmitted to people through the bites of infected female Anopheles mosquitoes. According to WHO data, malaria causes approximately 400,000 deaths a year, and the African region has the highest burden of the disease, with an estimated 93% of the cases (WHO, 2020b). Malaria is particularly dangerous for children under 5, pregnant women, immunocompromised individuals, and older adults who are less likely to survive the disease (Caminade, McIntyre and Jones, 2019). Furthermore, the Lancet Commission report has observed that "[i]n 2015-19 suitability for malaria transmission in highland areas was 38.7% higher in the African region and 149.7% higher in the Western Pacific region compared with 1950s baseline" (Watts *et al.*, 2021, p. 11).

Figure 3: Mosquito Anopheles



Source: Barcelona Institute for Global Health (Huijben, 2016)

Malaria is considered a climate-sensitive disease because many factors impact the development of the disease, and as explained by Caminade, McIntyre and Jones (2019):

> Rainfall creates suitable conditions for mosquito-breeding sites, and temperature conditions modulate the development, aggressiveness, and mortality of the vector while also impacting the incubation period of the Plasmodium parasite inside the mosquito vector. There is a suitable temperature window for malaria transmission; if the local climate is too cold (<18°C for P. falciparum), it takes too long for the parasite to develop within the mosquito vector, while if the local climate gets too warm (>37°C), mosquito survival decreases dramatically. This is why tropical high-lands and desert areas are generally malaria-free.

Rainfall patterns, temperature, and humidity changes are, hence, all conditions that impact mosquitoes' ability to survive and transmit malaria. Some estimates predict that global warming could lead to a 12-27% increase in malaria prevalence (El-Sayed and Kamel, 2020). Some studies have already projected that warmer temperatures will likely affect malaria trends in highlands regions of East Africa and in places like Colombia and Ethiopia (Fouque and Reeder, 2019). Other studies have also projected changes in malaria distribution and increased transmission in the highlands of Africa, Latin America, and Southeast Asia (Bardosh *et al.*, 2017). Other elements also play a role in the disease's current distribution and increase the disease's risk, including population change, draughts, irrigation systems, and inadequate housing (Bardosh *et al.*, 2017).

In the East African region, the warming of the highlands will likely create more adequate conditions for malaria transmission in areas where it was very low or where the disease was not present (Githeko, Ototo and Guiyun, 2012). According to a Lancet study, "[c]limate conditions affect the range and reproductive rates of malarial mosquitoes and also affect the lifecycle of the parasitic protozoa responsible for malaria. The links between climate change, vector populations and hence malarial range and incidence may become significant in areas where the temperature is currently the limiting factor, possibly increasing the incidence" (Watts *et al*., 2015). Some models have pointed out that given the optimal temperature needed for malaria transmission (30-32°C), areas that are projected to become warmer might also experience a shift in the incidence of the disease and an eventual die out of the disease (Ngarakana-Gwasira *et al.*, 2016). In contrast, other studies have found that the vectors might already be adapting to water scarcity and changing breeding sites to increase survival even in the face of rising temperatures (Chadee and Martinez, 2016). Therefore, even if there are projections that warmer areas might see a decline in malaria cases other studies point to the possibility that mosquitoes' adaptation will allow them to survive to the rising temperatures.

Furthermore, recent studies have also highlighted that:

> The occurrence of vector competent Anopheles species and favorable climatic conditions autochthonous malaria cases may re-emerge in countries where malaria was previously eradicated. Since the late 1990s, locally transmitted cases have been reported in Germany, the Netherlands, Spain, France, Italy, Greece and Turkey. In general, malaria transmission in Europe is highly seasonal owing to temperate climatic conditions. The Mediterranean area, with mild and wet winters and hot and dry summers, has been and still is suitable for malaria transmission (Hertig, 2019).

Therefore, thinking through the needed strategies to address these malaria transmission changes in the face of climate change will be of particular concern to developing countries already struggling to contain the disease.

Resistant malaria

The situation of malaria is already of concern for many developing countries. This is even more the case when climatic conditions can jeopardize current gains in controlling the disease because of the likely expansion to higher altitude areas where it was not present. Another concerning element is the parasite's growing resistance against treatments such as anti-plasmodium drugs and the Anopheles mosquitoes' resistance to insecticides (El-Sayed and Kamel, 2020). Resistance to artemisinin (ART)[2] derivatives has already been widely documented in the Mekong subregion. This includes Cambodia, Thailand, Vietnam, Myanmar, and Laos. Resistance to other drugs such as piperaquine and mefloquine has also been found there (Uwimana *et al.*, 2020). The resistance to these treatments is of particular concern because of the potential to reach other areas of the world where it could have an even more significant impact. Based on a study published in *Nature*, a report of the BBC has documented resistance to artemisinin in the African region for the first time (Gallagher, 2020). This news has severe implications and could further complicate current efforts to reduce the burden of the disease.

Another component of the emergence of resistance is the resistance to insecticides among the Anopheles mosquitoes. According to the WHO, "73 countries have reported mosquito resistance to at least 1 of the 4 commonly-used insecticide classes in the period 2010-2018. In 27 countries, mosquito resistance was reported to all of the main insecticide classes" (WHO, 2020b).

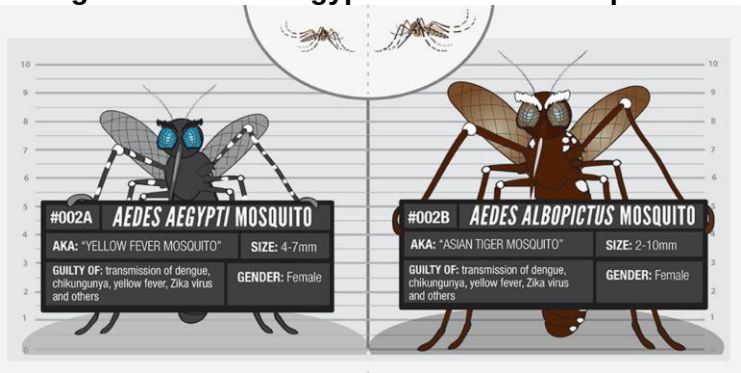
Other factors aggravating malaria include the disruptions to the existing malaria control program brought about by the current COVID-19 pandemic. A study in The Lancet has found that "[u]nder pessimistic scenarios, COVID-19-related disruption to malaria control in Africa could almost double malaria mortality in 2020, and potentially lead to even greater increases in subsequent years. To avoid a reversal of two decades of progress against malaria, averting this public health disaster must remain an integrated priority alongside the response to COVID-19" (Weiss *et al.*, 2020). Therefore, it is vital to ensure that that progress is not further disrupted and that health systems are prepared to continue providing critical services even when external shocks such as pandemics happen. This is even more essential in the face of climate change and the increase of resistance to treatment and to insecticides.

The case of dengue

Dengue is a viral infection transmitted by female mosquitoes of the species *Aedes aegypti* and, to a lesser extent, *Ae. Albopictus*. These mosquitoes are also known to be vectors of chikungunya, yellow fever, and Zika viruses (WHO, 2020c). According to the WHO, as noted above, "more than 3.9 billion people in over 129 countries are at risk of contracting dengue, with an estimated 96 million symptomatic cases and an estimated 40,000 deaths every year" (WHO, 2020a). Moreover, dengue is a disease mostly found in the tropics and the risk of being infected can vary due to rainfall, temperature, humidity and an increase in urbanization (WHO, 2020c). The dengue virus's ideal temperature ranges from 20 to 35°C (Fouque and Reeder, 2019). The virus that causes dengue is DENV. There are four DENV serotypes and therefore, an individual can be infected with each of the different serotypes, causing up to 4 infections (CDC, 2019).

[2] The WHO report on antimalarial drug efficacy, resistance and response: 10 years of surveillance (2010-2019) defines ART as: "Artemisinin resistance typically refers to a delay in the clearing of all parasites within a three-day period among patients infected with artemisinin-resistant strains of malaria. As a result, the artemisinin compound is less effective in clearing all parasites within a 3-day period among patients who are infected with artemisinin-resistant strains of malaria" (see https://www.who.int/publications/i/item/9789240012813).

Figure 4: Aedes Aegypti and Aedes Albopictus



Source: Barcelona Institute for Global Health (Paaijmans, 2016)

The mosquitoes that spread dengue are particularly well adapted to urban environments and can quickly reproduce in containers such as tires, pots, and water storage crates (Bardosh *et al.*, 2017). Other factors that favor the spread include unplanned urbanization, trade, demographic change, inadequate water supplies and warming temperatures (Ebi and Nealon, 2016). These factors have been linked to increases in the two main vectors' population and, therefore, further spread the dengue viruses—the WHO has documented a fast surge in the frequency of outbreaks worldwide. In the 1970s, dengue was only registered in 8 countries; now it is present in around 128 countries, making it the "fastest spreading mosquito-borne viral disease in the world" (WHO, 2019). Dengue epidemics are subjected to seasonal patterns and therefore, the transmission is highest during and after rainy seasons. Other factors that contribute to the increase include "high mosquito population levels, susceptibility to circulating serotypes, favourable air temperatures, precipitation and humidity, all of which affect the reproduction and feeding patterns of mosquito populations, as well as the dengue virus incubation period" (WHO, 2020c). Some of the countries that have experienced important expansions in the number of cases, as of 2020, include Bangladesh, Brazil, Ecuador, India, Indonesia, Sri Lanka and Thailand among others (WHO, 2020c).

Because dengue is mostly found in urban environments, current temperature changes in cities resulting from the warming climate are likely to enhance dengue transmission and outbreaks because of higher temperatures during the day (Fouque and Reeder, 2019). A study about the 2017 dengue outbreak in Sri Lanka has found that "global warming and adaptation of the transmission vector to a range of environmental and climatic conditions have combined to enable the advance of dengue into areas which in the past remained free from dengue" (Ali *et al.*, 2018). Other studies have also projected that increases in temperature and changes in rain patterns will benefit the vectors' geographical expansion. Therefore, the spread is expected in places where current temperatures are not suitable for Aedes reproduction. This will mostly occur in developing countries already experiencing high disease burdens (Ebi and Nealon, 2016). Areas in Europe, the United States and Canada are also likely to experience increases in outbreaks, though the significant expansions are projected in high altitude regions in the tropics (Ryan *et al.*, 2018). Because dengue and other vector-borne diseases are sensitive to temperature and rainfall changes, which will be exacerbated by climate change, epidemics are likely to occur in unprepared places to respond to these new events (WHO, 2012).

One of the regions where large outbreaks have been observed is in the Americas, including Brazil that in 2016 reported around 1.5 million cases (WHO, 2020c). Major epidemics have occurred, particularly in Brazil's crowded urban areas (Bardosh *et al.*, 2017). Many studies have shown that an increase in the disease burden will respond to broader dengue cases as more places will become more suitable due to climate change (Xu *et al.*, 2020). Therefore, increased efforts to limit global warming could restrict dengue expansion to areas where the incidence is currently low (Colón-González *et al.*, 2019).

The figure below from the Lancet Countdown report 2020 provides a visual illustration of the trends on the climate suitability of malaria and dengue from 1950 to 2020.

Figure 5: Change in climate suitability for malaria and dengue

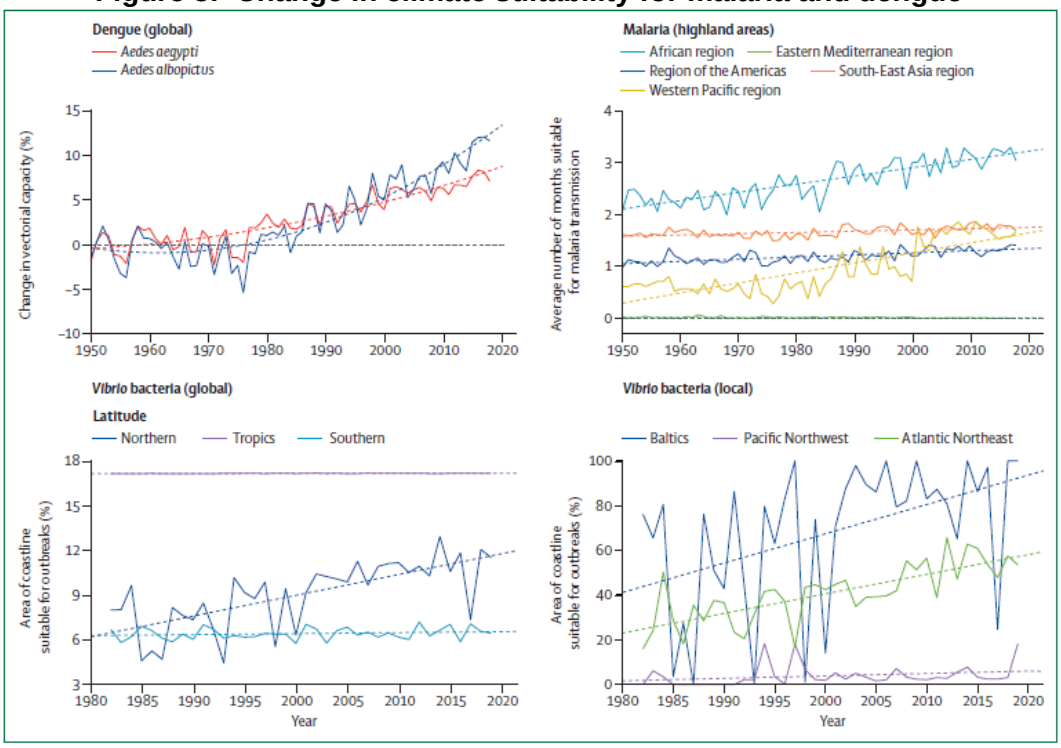


Figure 5: **Change in climate suitability for infectious diseases**
Solid lines represent the annual change. Dashed lines represent the trend since 1950 (for dengue and malaria) and 1982 (for *Vibrio* bacteria).

Source: (Watts *et al.*, 2021, p. 12)

This figure confirms that urgent action is needed to address the fast expansion of these diseases.

4. RESPONSES TO THE HEALTH IMPACTS OF CLIMATE CHANGE

Data and information on the climate change risks to health and the capacity to assess and manage these are fundamental to reduce health implications. Climate prediction and information services help countries detect looming extreme weather events and monitor changes and variability of the climate over the short and long run. Early warning systems are one of the essential tools for efficient climate risk management. Such methods and the observation of temperatures, rainfall and humidity, are critical to identifying potential changes in the distribution of vectors and vector-borne diseases, such as dengue and malaria (Fox *et al.*, 2019; Guillemot, Adebola and Platzer, 2011). The data and findings from climate and meteorological surveillance can inform public health systems and national policies. The information can further be used to increase the health sector's capacity to make sound health decisions that take into account the risks from climate variability and climate change. This will allow countries to strengthen the health sector's climate resilience and the information systems can further support identifying gaps in existing climate information services.

Early studies on using climate information to predict epidemics found that "climate information can be used to improve epidemic prediction, and therefore has the potential to improve disease control. To make full use of this resource, however, it is necessary to carry out further operational development. The true value of climate-based early warning systems will come when they are fully integrated as one component in well-supported systems for infectious disease surveillance and response" (Kuhn *et al.*, 2005, p. 8). Therefore, disease early warning systems and epidemiological surveillance are essential pillars in managing the climate-related risks to health and should be part of adaptation strategies to provide better tools to control disease outbreaks. For example, "[o]ne general strategy for adaptation in the health sector is epidemiological surveillance which can provide an early detection of changes in incidence, mortality and geographic range of health outcomes associated with climatic change. This would be achieved through regular reporting of specific health outcomes and routine statistical analysis of the data" (Confalonieri, Menezes and de Souza, 2015).

The surveillance and assessment as part of both the health and climate information systems need to work together to prepare and implement climate and health policy responses (WMO, 2014).The Lancet Countdown for 2020 reports that "[a] total of 86 national meteorological and hydrological services of member states of the World Meteorological Organization reported providing climate services to the health sector, an increase of 16 from the 2019 report" (Watts *et al.*, 2021, p. 17). The Lancet report's information illustrates current efforts linking information systems from climate to health, but to have a more significant impact these services will need to be further expanded.

Fox *et al.* have further highlighted that past research has shown that "… climate-related health outcomes are often affected (and sometimes even determined) by service quality in sectors other than health" (Fox *et al.*, 2019). This refers to sectors such as energy, transport, water and sanitation, or urban planning. These sectors are interlinked, and service deficiencies in one or more sectors can constrain the others' adequate functioning, with often implications on health and well-being in the long term. Responses to the health risks from climate change and variability should also envisage a cross-sectoral approach and not just be limited to the health sector.

Policy frameworks and initiatives at global and national levels

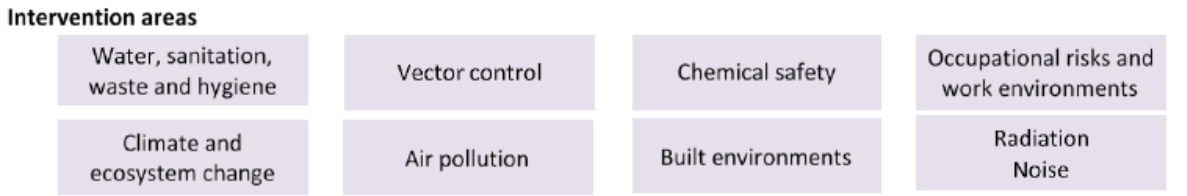
There are various policy frameworks and initiatives that have acknowledged the impacts of climate change on health, including on the transmission patterns of infectious diseases. As noted above, the World Health Organization (WHO), as the leading multilateral organization

specialized in health, has, for instance, approved through the World Health Assembly (WHA)[3] a series of resolutions on health and climate change. One of the first resolutions in this area (Resolution WHA61.19) was approved in 2008, which noted that the distribution of vector-borne diseases is affected by climatic changes along with other health issues. The resolution also called on Member States "to develop health measures and integrate them into plans for adaptation to climate change as appropriate" (World Health Assembly, 2008). Following the resolution, the WHO has drafted a series of work plans on climate and health[4], which are based on four pillars: advocacy, partnerships, science and evidence, and health system strengthening.

The WHO has produced a series of reports outlining the different intersection areas of health and climate change, including a recent guidance document called 'Climate Resilient and Environmentally Sustainable Health Care Facilities'[5]. This document aims to provide tools and interventions to "strengthen health care facilities in the context of climate change. The aim is to enable health care facilities to anticipate, respond to, recover from and adapt to climate-related shocks and stresses" (WHO, 2020d). The document acknowledges the key role that health care facilities will need to play in providing services and anticipating shocks, including changes in outbreaks and patterns of diseases. The overall strengthening of the health sector was identified as critical in responding to climate change.

The WHO has also produced other documents to help advice the health sector on adaptation strategies regarding climate change impacts. In 2019, the WHO presented a 'WHO global strategy on health, environment and climate change: the transformation needed to improve lives and well-being sustainably through healthy environments'[6]. The strategy aims to provide a vision on how the health community needs to respond to health risks until 2030. The strategy elaborates on the different areas of intersection between health and climate change and also points out the need to continue addressing knowledge gaps to generate better evidence on health risks related to climate change. The document also emphasizes the need to increase the health sector's ability to provide policy guidance to other sectors and strengthen intersectoral assessments (World Health Assembly, 2019). The figure below provides an overview of the intervention areas identified by the WHO in the strategy.

Figure 6: Identified intervention areas of health and climate change by the WHO



Source: (World Health Assembly, 2019)

Figure 6 provides an overview of all the critical areas where the health sector should be involved in designing intervention strategies at the intersection of health and climate change, including vector control.

Another critical framework at the multilateral level is the WMO's Global Framework for Climate Services (GFCS) to facilitate and improve climate and meteorological information

[3] The World Health Assembly is the forum through which the World Health Organization is governed by its 194 Member States. It is the world's highest health policy setting body and is composed of health ministers from Member States. See https://www.who.int/about/governance/world-health-assembly.
[4] E.g. 'WHO work plan on climate change and health 2008 – 2013' and 'WHO work plan on climate change and health 2014 – 2019'
[5] See full document here: https://www.who.int/news/item/12-10-2020-who-publishes-guidance-on-climate-resilient-and-environmentally-sustainable-health-care-facilities
[6] See the full document here: https://apps.who.int/gb/ebwha/pdf_files/WHA72/A72_15-en.pdf

systems. The GFCS has defined public health as one of its five key priorities[7] and aims, on the one hand, to make climate information more readily available to the health sector for operational and strategic use and, on the other hand, to encourage the climate service community to respond to the climate information-related needs of the health sector at all levels. By bridging these gaps, the GFCS expects to "support health priorities such as improving disease surveillance, and extending the lead-time to prevent and prepare for climate related outbreaks and emergencies" (Global Framework for Climate Services, 2020).

Another international initiative is The *Lancet* Countdown on health and climate change, which is published annually. It is a global, multidisciplinary collaboration dedicated to monitoring the evolving health profile of climate change. The annual report aims to provide an independent assessment of the progress against the goals set out in the Paris Agreement. It provides information on the findings of 35 leading academic institutions and UN agencies.[8] The report also helps to assess, through several indicators, the progress on the different areas that intersect health and climate change.

At the national level, governments at both national and sub-national levels play a crucial role in climate change and health policy. Climate adaptation planning often serves as an essential mechanism in defining and guiding country-level initiatives (Fox *et al.*, 2019).This is also in line with the WHO's guidance to develop and include health-related measures into plans for adaption to climate change. The following section will look at two examples of national level adaption plans and examine the integration of health aspects with a particular emphasis in infectious diseases.

[7] The other priority areas are 'agriculture and food security', 'disaster risk reduction', 'energy' and 'water'.
[8] Information on the Lancet reports can be found here: https://www.thelancet.com/countdown-health-climate

5. HEALTH IN NATIONAL CLIMATE POLICIES: TWO EXAMPLES

National Adaptation Plans

The Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC), established at COP16 in Cancun, Mexico, the national adaptation plans process to promote the formulation of climate change adaptation plans at the national level. The Convention requires the Parties to the Convention to make different commitments, one of which is drafting national plans detailing the adaptation strategies to climate change. These plans guide the countries in identifying the critical risks that climate change poses on a country and, more importantly, how they can build resilience against the impacts of climate change. In this regard, the National Adaptation Plan (NAP) serves countries to analyze the climate adaptation needs in the medium and long term and subsequently design and implement strategies and programs that address these needs.

Countries have been working on creating NAPs to identify risks and the strategies for adaptation. Examining the elements of NAPs and the areas of risks the NAPs have singled out can indicate whether climate change and health linkages are being integrated into the adaptation efforts of countries affected by climate-sensitive diseases. In general, NAPs and other adaptation plans do recognize the impacts of climate change on health. Still, they will need to increase their efforts to link climate information with health sector activities (WMO, 2014). As examples on how countries have integrated health into their National Adaptation Plans, two NAPs will be examined, one from the East African region, Kenya, and one from Latin America, Brazil. These two examples help to illustrate some of the ways in which countries are considering health risks alongside climate change. East Africa and Latin America are two regions that have been identified as places where changes in the patterns of vector-borne diseases will be observed. Furthermore, both countries currently experience high burdens of malaria and dengue.

Kenya's National Adaptation Plan

Kenya's NAP has identified different hazards and vulnerabilities that are linked to climate change. These include mainly droughts, floods and sea-level rise. Among these, droughts were identified as the most severe challenge that the country has been facing. Multiple droughts have occurred in the past few decades and constrained both the country's economy and its people's health and well-being. Droughts have triggered far-reaching losses of crops and livestock, resulting in famines and populations' internal displacements (Government of Kenya, 2016).

The second hazard identified in the NAP is floods. The NAP has highlighted that, while floods have been taking place relatively frequently, the annual rain seasons have become heavier, with sudden and late onsets causing flash flooding and inundation. The economic fallout arising through this type of disaster is estimated at 5.5% of Kenya's GDP every seven years. On the health side, the report describes that floods are the reason for 60% of disaster victims. And that "[d]uring flood events there is often an upsurge in water-borne or sanitation-related diseases, such as typhoid, cholera, malaria and diarrheal diseases" (Government of Kenya, 2016, p. 17). This section of the national action plan already recognizes that infectious diseases such as malaria are health events that will need to be considered. Furthermore, the plan also points out that floods can also damage critical infrastructures such as water supply and transport networks that might hinder the provision of basic services to the population, including essential health services. Poor urban infrastructure and urbanization are further factors that can increase vulnerability to flooding in urban areas and

in turn could increase the spread of vector-borne, water-borne, and sanitation-related diseases.

In the case of Kenya's NAP there are some provisions that have been included to address some of these climate change-induced health risks including strengthening the integration of climate change adaption into the health sector. The NAP proposes a set of adaptation actions tailored for different sectors of relevance to the country's development, including the health sector. As part of this framework, the NAP envisions the following areas of actions to be pursued, ranging from short to the long term actions:

- Undertake a climate vulnerability and risk assessment of the impacts of climate change and variability on human health.
- Increase public awareness and social mobilization on climate change and impacts on health.
- Design appropriate climate change-related interventions for the health sector.
- Design appropriate measures for surveillance and monitoring of climate change-related diseases to enhance early warning systems, including improving existing databases on health sector indicators, amongst others.
- Upscale results of pilot projects in climate change adaptation in the health sector.

It further suggests accounting for the climate change-induced health risks by strengthening the integration of climate change adaption into the health sector. Kenya's Adaption Plan details health risks arising from the slow onset and sudden climate events such as droughts or floods, but it provides less attention to the changes in patterns of infections resulting from vector-borne diseases. However, it does recognize that increases in diseases such as malaria and other vector-borne diseases may present further challenges, even if it sees these as lower risk compared with other climate change-related aspects. Therefore, strengthening the overall health infrastructure will provide better tools to deal with the shocks to the health system of infectious diseases and other challenges identified by the country.

Brazil's National Adaptation Plan

Brazil's NAP offers a detailed plan elaborating on the risks and hazards arising from climate and environmental change and presents a strategic adaptation approach at the sectoral level. The NAP identified 11 sectors critical to Brazil's development that need to build their resilience. 'Health' is one of the key sectors that have been identified together with: Agriculture, Biodiversity and Ecosystems, Cities, Disaster Risk Management, Industry and Mining, Infrastructure (Electric Power, Transport and Urban Mobility), Vulnerable Communities, Water Resources, Food and Nutritional Security, and Coastal Zones. For each of these critical sectors, the NAP discusses the "main vulnerabilities, knowledge gaps, and management of each sector and topic, from a climate-change perspective and present[s] current guidelines for implementation of adaptation measures targeted at increasing climate resilience" (Government of Brazil, 2016).

The plan addresses the health dimension in its dedicated section for the health sector but it also refers to health impacts in other sectoral plans, such as 'Disaster Risk Management', 'Vulnerable Communities' and 'Food and Nutritional Security'. The NAP discusses various health impacts arising from climate change triggered by either the repercussions from (1) sudden climate and environmental events or (2) slow-onset climate and ecological changes. Both clusters of events can directly or indirectly trigger an increased exposure of populations to diseases, higher food insecurity and malnutrition and material losses while also deteriorating other areas of socio-economic and human development. Vulnerable and more impoverished segments of society are even more exposed to such impacts. Furthermore, Brazil's NAP acknowledges the constraints that are anticipated for the national healthcare

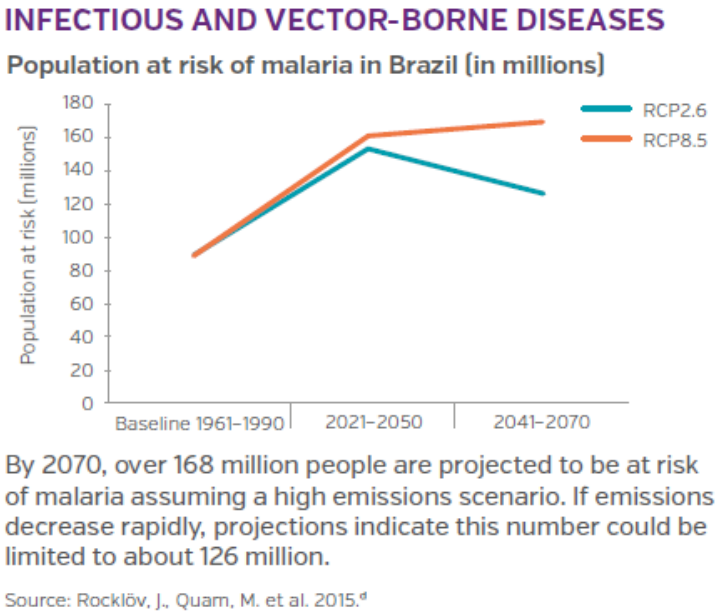
system, the Unified Health System (Sistema Único de Saúde - SUS), deriving from growing exposures to the impacts of climate change on its population. Some of the foreseen impacts to the SUS include the overburdening of health facilities due to a rise in hospitalizations and deaths, disruption of service networks, the potential impact of climate events on transport infrastructure and hospital buildings, impact on healthcare equipment and staff or also the re-emergence of previously controlled diseases.

The adaptation plan for the health sector clusters the health risks associated with climate change into four groups. The first concerns the exposure to disasters such as flooding and drought. The second group of health risks in the NAP concerns the impact of air pollution. Constraints in the supply of adequate water resources are identified as the third group of health risks and the fourth group of health risks comprises infectious diseases sensitive to the climate. The adaptation plan explains that the health consequences of the four clusters of health risks are not limited to the immediate health impacts such as deaths and injuries but can also lead to mental and cardiovascular problems, malnutrition, and a medium-term increase in infectious diseases and epidemics. In particular under the section of infectious diseases sensitive to climate change, the NAP stresses that climate change has the potential to "…expand areas susceptible to transmission of infectious diseases […] and to the emergence of new diseases and re-emergence of known ones" (Government of Brazil, 2016, p. 166).

A broad set of climate, environmental and socio-economic circumstances have an influence on the emergence and spread of infectious diseases in the climate change context. These include for instance, changes in the environment, such as fluctuations and peaks in temperatures, rainfalls and extreme weather events. Land use and housing pattern change, especially in natural and forest territories, proximity to hazardous locations, and social status are among the determinants that would influence the likelihood to be exposed to infectious diseases particularly vector-borne ones. Access or constrained access to water supply chains, sanitation, and health care facilities are essential aspects that were also listed. The combination of these factors with climate variability can lead to a range of infectious diseases: "… the main infectious and endemic diseases relating to climatic variability that afflict the population are: dengue fever, malaria, yellow fever, Chagas disease, cutaneous and visceral leishmaniasis, schistosomiasis, trachoma, leptospirosis, viral hepatitis, acute diarrhoeal diseases, cholera, acute respiratory infection, influenza syndromes (influenza and other agents) and severe acute respiratory syndrome (SARS) among others" (Government of Brazil, 2016, p. 173).

Furthermore a projection published by the Pan-American Health Organization shows the potential increase of malaria in Brazil due to climate change. Below is the graph illustrating the projection risk for the population.

Figure 7: Population at risk of malaria in Brazil



Source: (World Health Organization and United Nations Framework Convention on Climate Change, 2015)

Brazil's National Adaptation Plan offers a strategic approach to build the resilience of each of the country's eleven critical sectors to manage and lower the impact of and vulnerabilities to climate change. This includes clear proposals for actions, strategies, and guidelines relevant to the public sector's institutional framework, policymaking at various governance levels, and national development strategies. The NAP provides a detailed breakdown of the main challenges for health and well-being and emphasizes on the need to address them appropriately. The adaptation plan addresses infectious diseases, including vector-borne diseases, and contextualizes the occurrence of such diseases and the potential changes in the patterns of infections due to climate change. It acknowledges the exposure to infectious diseases as a critical issue in adaptation planning. Preparing for changes in vector-borne diseases such as malaria and dengue would need to be integrated as part of other strategies to strengthen the health system. Continued surveillance of the current situation of infectious diseases in the country and the monitoring of changes will help foresee where more capacities and resources may be needed to anticipate changes.

One of the key challenges with NAPs for developing countries is going to be accessing the financial resources to adequately help them adapt and create resilience in their systems including adapting and strengthening their health systems. There are several international agreements on climate change that have included financial commitments to assist developing countries. The Paris Agreement, which is a legally binding international treaty on climate change, was adopted by 196 Parties at the Conference of the Parties (COP21) in Paris, on 12 December 2015 and entered into force on 4 November 2016. The Paris Agreement "reaffirms that developed countries should take the lead in **providing financial assistance** to countries that are less endowed and more vulnerable" (emphasis added, UNFCCC, 2020). Moreover, the treaty also recognises that "[c]limate finance is equally important **for adaptation**, as significant financial resources are needed to adapt to the adverse effects and reduce the impacts of a changing climate"(emphasis added, UNFCCC, 2020). The health challenges that will result from the impacts of climate change should be an important aspect to include in the financial resources that will be needed for developing countries and examining what is currently available and what will be needed would also be critical.

6. POLICY RECOMMENDATIONS

Developing countries face multiple challenges arising from climate change. The impact of climate change on the health sector should be an important consideration as countries develop their national strategies both for the climate sector as well as for the health sector. Some of the areas that would need to be considered include:

- In developing countries, the health systems already face many vulnerabilities, including lack of appropriate surveillance systems, early warning systems and challenges related to access to treatments, vaccines, and diagnostics. Increasing investment in research on climate change and health and building monitoring and surveillance systems would be essential for supporting health systems to prepare. Furthermore, it would also be necessary to monitor changes in conditions such as rainfall, temperature and humidity that could help map the risk of outbreaks of diseases such as dengue and malaria and help prevent them from spreading in new geographical areas.
- Climate prediction and information services help countries detect looming extreme weather events and monitor changes and variability of the climate over the short and long run. Early warning systems are essential tools for efficient climate risk management; therefore setting up these systems can help generate useful data. Those findings from climate and meteorological surveillance systems can then help inform public health systems and national policies. Health and climate information systems need to work together to prepare and implement climate and health policy responses.
- In the case of vector-borne diseases, it will be essential to build understanding and local scientific knowledge related to the risk of emergence in new geographical zones triggered by climate change. Therefore, more focus on research in developing countries will help build knowledge and capacity in this area.
- Developing counties will need to be supported to continue to provide essential health services in the face of outbreaks or other health emergencies. Improvements in public health services and strengthening primary health care will help reduce mortality and morbidity resulting from the growing number of dengue and malaria infections.
- Adequate climate finance should be made available. Developed countries will need to take the lead in providing financial assistance to developing countries to help adaptation strategies that include strengthening health systems to adapt to climate change and health risks, including building adequate health infrastructure, access to clean water and sanitation.
- Prepare health systems, individuals, and societies to adapt to infectious diseases' changes and their patterns of infections by strengthening diagnostics systems, access to appropriate therapies, and increasing preventive measures regarding vector control.
- There is a need to strengthen and increase multisectoral collaboration between the environment and the health sectors and find spaces where the health sector can provide policy guidance to other sectors.

7. CONCLUSIONS

The paper has explored a few of the challenges related to climate change, and its impact on health, specifically the cases of malaria and dengue. As countries continue to design and implement strategies to deal with climate change, the health dimension must be adequately integrated into national strategies and international commitments should also include the health aspect. Temperature, rainfall, and humidity variations will increase the geographical expansion of infectious diseases and their infection patterns, resulting in an increase of vector-borne diseases including malaria and dengue, putting additional pressure on the health sector. The increased cases of malaria resistance will be particularly challenging for malaria eradication programs. Integration of the impact of vector-borne diseases as part of climate change response is particularly important in developing countries with high burdens.

Climate change National Adaptation Plans offer countries the opportunity to map out the areas with high risks from climate change and those for which financial and technical support will be most needed. Climate-induced changes in vector-borne diseases make it clear that health systems will need to be strengthened to become more resilient and be adapted adequately to face the additional health challenges arising from climate change.

This paper provides two examples of how countries have begun integrating health in National Adaptation Plans to respond to climate change. However, ensuring that adequate financial support is made available for developing countries to implement those plans continues to be a challenge that requires further attention and research.

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ISSN 1819-6926