RICCAR

Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region

Climate Change Impacts on Health in the Arab Region:

A Case Study on Neglected Tropical Diseases

TECHNICAL REPORT

UNITED NATIONS UNIVERSITY
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PREFACE

The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) is a joint initiative of the United Nations and the League of Arab States launched in 2010.

RICCAR is implemented through a collaborative partnership involving 11 regional and specialized organizations, namely United Nations Economic and Social Commission for Western Asia (ESCWA), the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), Food and Agriculture Organization of the United Nations (FAO), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the League of Arab States, Swedish Meteorological and Hydrological Institute (SMHI), United Nations Environment Programme (UN Environment), United Nations Educational, Scientific and Cultural Organization (UNESCO) Office in Cairo, United Nations Office for Disaster Risk Reduction (UNISDR), United Nations University Institute for Water, Environment and Health (UNU-INWEH), and World Meteorological Organization (WMO). ESCWA coordinates the regional initiative. Funding for RICCAR is provided by the Government of Sweden and the Government of the Federal Republic of Germany.

RICCAR is implemented under the auspices of the Arab Ministerial Water Council and derives its mandate from resolutions adopted by this council as well as the Council of Arab Ministers Responsible for the Environment, the Arab Permanent Committee for Meteorology and the 25th ESCWA Ministerial Session.

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ACRONYMS AND ABBREVIATIONS

ACL	Anthroponotic Cutaneous Leishmaniasis
AR5	Fifth Assessment Report (IPCC)
CL	Cutaneous Leishmaniasis
DALY	disability adjusted life years
IPCC	Intergovernmental Panel on Climate Change
Km	kilometres
Km^2	square kilometres
m/s	metres per second
MENA	Middle East North Africa
NTD	neglected tropical disease
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RICCAR	Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
T_{ave}	average temperature
T_{max}	maximum temperature
T_{min}	minimum temperature
Tw	wet-bulb temperature
VL	Visceral Leishmaniasis
WADI	Water Associated Disease Index
ZCL	Zoonotic Cutaneous Leishmaniasis
°C	degree Celsius
%	per cent

EXECUTIVE SUMMARY

The Arab region is experiencing widespread environmental and social changes that have important implications for human health. Acting through direct and indirect pathways, climate change is expected to change patterns of communicable and non-communicable disease incidence in the region, and decision-makers require information on these projected trends to ensure appropriate planning decisions to protect and promote human health.

This study examines the impact of climate change on two important Neglected Tropical Diseases (NTDs) in the region. The Water-Associated Disease Index (WADI) approach, developed to assess multi-dimensional vulnerability to health hazards in the face of global change, is extended to the case of leishmaniasis and schistosomiasis. This study particularly focuses on exposure dimensions to understand how climate change will impact conditions required for the transmission of leishmaniasis and schistosomiasis. Bias-corrected Regional Climate Modelling (RCM) projections developed for the Middle East North Africa (MENA) domain as part of the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) were used, and were integrated with other indicators of exposure. An assessment of historical exposure conditions for both diseases was then produced and compared to those for mid- and end- of century using RCP 4.5 and RCP 8.5 emission scenarios.

In the case of schistosomiasis, the results indicate that while transmission has historically been limited during colder months, increasing temperatures will create conditions that intensifies infection risk during winter months. In the case of leishmaniasis the results indicate that projected warmer temperatures during colder months could extend the period of suitability for disease transmission. These changes in exposure are projected to occur in some areas where populations experience higher levels of susceptibility and lack of adaptive capacity.

In particular, leishmaniasis presents a greater threat to the health and socioeconomic status of women who work in agriculture and animal care as they may be exposed to sand fly bites, while also having restrained coping capacity such as limited access to financial resources for healthcare. This can also result in negative impacts on psychological wellbeing and quality of life due to social stigmatization associated with disfiguring scars. Impacts of water-related diseases such as schistosomiasis are also characterized by gender-based vulnerability in regions where women and children bear the burden of water-related tasks around the household. Understanding these vulnerabilities is critical for public health decision-makers in order to target marginalized groups and reduce disproportionate climate change impacts on the burden of disease.

1 BACKGROUND

1.1 Introduction

Climate change has the potential to threaten health and wellbeing in the Arab region by influencing patterns of communicable and non-communicable diseases transmission. These transmission patterns occur through a range of direct and indirect pathways characterized by complex interactions. Direct effects include increases in heat-related illnesses and extreme events, while indirect effects include declines in air quality, changes to the distribution of disease vectors, undernutrition, and mental health impacts associated with displacement and loss of livelihoods.[1] A better understanding of these impacts and of marginalized groups most affected is needed to improve public-health decision-making and to ensure mitigation and adaptation strategies do not impinge on health.

The goal of this assessment is to provide an overview of climate change impacts on health in the Arab region and a detailed study on two important Neglected Tropical Diseases (NTDs) in the region. NTDs are a group of infectious diseases which disproportionately impact the poorest people in tropical and subtropical regions. Many of them are chronic parasitic infections which reinforce poverty by impacting child development, worker productivity and pregnancy outcomes, costing developing economies billions of dollars every year.[2] Understanding how climate change will impact efforts to control and eliminate these diseases is of critical importance to reducing the infectious disease burden in the region. In the Arab region, Egypt and Yemen experience the highest rates of many NTDs, followed by Algeria, Libya, and Morocco.[3]

The case study focuses on leishmaniasis and schistosomiasis, two NTDs endemic to the Arab region that are sensitive to changing climate conditions. Cases in western North Africa and Egypt were selected for further investigation due to a high prevalence of leishmaniasis and schistosomiasis, respectively. Moreover, this selection was made given the availability of social and environmental datasets that are integrated with climate information.

1.2 Climate Change Impacts on Health in the Arab Region

The health impacts resulting from climate change will be experienced differently across diverse geographical areas and populations in the region. Varying exposure to health hazards as well as the susceptibility of different populations and their ability to cope or adapt will determine the overall impacts on human health and wellbeing. The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) indicates that there has “very likely” been an overall increase in the number of warm days and nights in the region.[4] These increasing temperatures lead to greater risks of heat-related morbidity and mortality in both high and low-income countries in the Arab region, predominantly in urban areas.[5] Extreme heat causes higher rates of hospitalization and mortality in certain groups including the elderly, people with existing conditions such as cardiovascular or respiratory disease, people living in lower quality housing as well as outdoor workers. While humans can adapt to changes in temperature, there are physiological limits that may be passed in some climate change scenarios.[6] For instance, sufficiently long periods of Tw > 35°C are thought to be intolerable, where Tw refers to a combined measure of temperature and humidity or degree of ‘mugginess’.[7] Additionally, warmer temperatures may magnify the effects of poor air quality such as ground-level ozone, and increase the production of airborne allergens which can further exacerbate respiratory diseases.

Diseases transmitted by waterborne or foodborne agents are sensitive to changes in temperature and are common in the Arab region. Higher rates of diarrhoeal disease caused by bacteria such as *Salmonella* and *Campylobacter* occur during warmer temperatures and are projected to rise due to climate change.[8] Transmission of pathogens associated with contaminated drinking water and certain food crops such as enteric viruses and *Cryptosporidium* has additionally been associated with precipitation patterns, including conditions of flooding and drought. Due to existing gender roles in many countries, this may particularly impact women and girls who spend large amounts of time performing water, sanitation and hygiene-related tasks, and caring for sick members of their families.

Vector-borne diseases including leishmaniasis, malaria, dengue, and schistosomiasis are also very sensitive to a range of climate variables, and constitute a major increasing public health concern in the region. Favorable climate conditions influence the growth, survival, and transmission of vectors and rising minimum and maximum temperatures may result in vector range changes or expansions. In addition, climate change can perturb ecosystems and habitats of zoonotic reservoir species, indirectly influencing disease transmission.[9]

In many parts of the Arab region, the impacts of climate change on agricultural production may also exacerbate existing levels of undernutrition, causing chronic diarrhea and leading to impaired development among children. Thus, threats to food security have significant implications for child health, and higher costs for food will disproportionately contribute to undernutrition in low-income households. Many of these climate change impacts on health are magnified in areas where other environmental changes or social and political crises occur, such as desertification or conflict.

1.3 Case Study General Methodology

This case study adapts the Water-Associated Disease Index (WADI) approach[10], which aims to improve understanding of vulnerability to health hazards associated with global changes, to the case of leishmaniasis and schistosomiasis in the Arab region. It brings together different types of information in the form of an index, comprising dimensions of exposure, susceptibility and adaptive capacity in order to identify regions most vulnerable to specific health hazards of interest. In this approach, vulnerability is defined as the propensity to be adversely impacted, and exposure is defined as the conditions that support the presence and transmission of a disease agent. Susceptibility refers to sensitivity when exposed to a hazard, which may include social, economic, and political conditions.[11] Adaptive capacity is defined as an ability to respond or adapt to a hazard. For example, access to healthcare would allow a population to better respond to an outbreak.

To identify components comprising exposure, susceptibility and adaptive capacity, conceptual frameworks were developed for leishmaniasis and schistosomiasis and were used to describe relationships between the disease agent, human health and the environment in the research literature, and their potential indicators. Based on these indicators and corresponding thresholds, datasets to populate indicators were identified and included in the assessment.[12] Selection of data was based on the quality and availability of datasets identified from publicly accessible data repositories online.

Regional Climate Modelling (RCM) projections developed for the Middle East North Africa (MENA) domain were used among other datasets to compare historical exposure conditions for both diseases to those for mid- and end- of century using RCP 4.5 and RCP 8.5 emission scenarios. In the case of leishmaniasis and in line with its conceptual framework, current and future exposure to the disease were assessed based on components for suitable temperature and humidity conditions for the sandfly vector that carries the disease, combined with an indicator on landcover types that support transmission of the zoonotic cutaneous form of the disease. In the case of schistosomiasis, current and future exposure was assessed based on a component for suitable temperatures for *B. alexandrina* snail populations that transmit *S.mansoni*, the schistosome parasite causing schistosomiasis, in the North Africa region.[13] Air temperature was used as a proxy for water temperature, which is not available in climate models. The temperature suitability component was integrated with a component on proximity to water sources and extent of sewage networks that impact the transmission cycle. Datasets for the exposure components and associated indicators were imported into a geographical information system (ArcGIS) and converted into raster format for manipulation with pixels representing a value from 0 to 1. To understand seasonal trends, temperature and humidity rasters were developed monthly.

As susceptibility and adaptive capacity components can be difficult to differentiate in empirical assessments (e.g. education level), these respective components were combined in this analysis to create one map output representing 'susceptibility and lack of adaptive capacity'.[14] These raster layers components contained pixels representing a value from 0 to 1, and were created by normalization. In the case of susceptibility, x represents the factor in question, and x_{min} and x_{max} represent the lowest and highest value in the dataset respectively (Equation 1).

$$\text{Susceptibility component } x = (x - x_{min})/(x_{max} - x_{min}) \quad (1)$$

The opposite was done in the case of adaptive capacity to create raster layers representing ‘lack of adaptive capacity,’ in order to combine these components with those of susceptibility.

To create map outputs, components were assumed to have equal importance and were aggregated to form composites for exposure, susceptibility and lack of adaptive capacity using an arithmetic average.[15] While equal weighting was used, other weighting approaches could be adopted with understanding of the local importance of these components, such as through expert weighting. Rather than creating an overall vulnerability index, these separate maps were created for each disease to highlight areas of particular concern for decision-makers.

2 LEISHMANIASIS IN NORTH AFRICA

2.1 Background on Leishmaniasis

Leishmaniasis is an endemic NTD in the MENA region and represents a significant health burden. The disease is caused by infection with a *Leishmania* parasite, transmitted by a sandfly vector. Globally, approximately 1.3 million cases of leishmaniasis occur annually, and approximately 1.7 billion people globally live in areas where they may be at risk of developing a form of the disease.[16] While leishmaniasis is estimated to cause the ninth largest disease burden of infectious diseases, it has received limited attention from policy-makers despite its importance.[17] Some *Leishmania* species cause a chronic disfiguring Cutaneous Leishmaniasis (CL), while others cause a lethal form of the disease known as Visceral Leishmaniasis (VL), which is the cause of around 70,000 annual deaths globally.[18] There is frequently little information on incidence because surveillance and reporting is limited in many countries affected by leishmaniasis.

The Zoonotic Cutaneous form of Leishmaniasis (ZCL) carried by animals and the Anthroponotic Cutaneous form (ACL) carried by humans are transmitted in the Arab region in rural arid areas and urban areas respectively. ZCL is widely distributed in areas with suitable types of vegetation to support the rodent carrier *P. obesus* while ACL is transmitted in areas with densely populated towns and villages and peri-urban areas.

The incidence of Cutaneous Leishmaniasis (CL) in selected Arab States is presented in Table 1. Foci of Zoonotic Cutaneous Leishmaniasis (ZCL), predominantly caused by *L. major,* occur in Algeria, Egypt, Iraq, Jordan, Libya, Morocco, Palestine, Saudia Arabia, Somalia, Syria, Sudan, Tunisia and Yemen, where the disease is transmitted by the fly *P. papatasi*. It is the dominant form in North Africa and causes 90% of cases. Anthroponotic Cutaneous Leishmaniasis (ACL) caused by *L. tropica* occurs in Iraq, Morocco, Saudi Arabia, Syria and Yemen and is transmitted by the fly *P. sergenti*.[19] In North Africa, only sporadic cases are reported for *L. infantum*, which is another species causing CL (Figure 1).

The western North Africa region was chosen for this case study because CL is a growing public health problem in the region and Morocco was chosen for a more detailed analysis of susceptibility and adaptive capacity because relevant datasets were available.

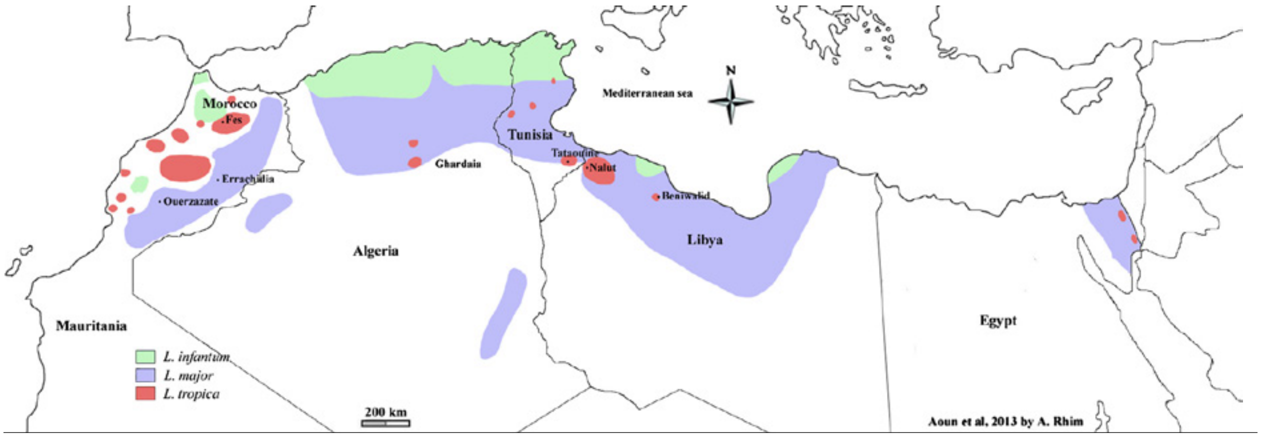
TABLE 1: Cutaneous leishmaniasis incidence in selected Arab States

Selected country	Cases reported per year	Years of report	Estimated annual incidence*	Main vector	Main reservoir host
Algeria	44,050	2004-2008	123,300-202,600	ZCL: *P. papatasi*	*Psammomys obesus*
Egypt	471	2008	1,300-2,200	ZCL: *P. papatasi*	*Psammomys obesus*
Iraq	1,655	2004-2008	8,300-16,500	ACL: *P. sergenti* ZCL: *P. papatasi*	Little information
Jordan	227	2004-2008	630-1,000	ZCL: *P. papatasi*	*Psammomys obesus*
Libya	3,540	2004-2008	9,900-16,300	ZCL: *P. papatasi*	*Psammomys obesus*
Morocco	3,430	2004-2008	9,600-15,800	ACL: *P. sergenti* ZCL: *P. papatasi*	*Meriones shawi*
Palestine	218	2005-2009	610-1,000	Little information	Little information
Saudi Arabia	3,445	2004-2008	9,600-15,800	ZCL: *P. papatasi*	*Psammomys obesus*
Sudan	NO DATA		15,000-40,000	ZCL: *P. papatasi*	Little information
Syria	22,882	2004-2008	64,100-105,300	ACL : *P. sergenti* ZCL : *P. papatasi*	*Psammomys obesus*
Tunisia	7,631	2004-2008	21,400-35,100	ZCL: *P. papatasi*	*Psammomys obesus*
Yemen	603	2005-2009	3,000-6,000	ACL: *P. sergenti ?* ZCL: *P. papatasi*	*Rock hyrax;* *Procavia capensis ?*

* The values are based on reported incidence and underreporting rates. This column thus provides an estimate of the actual number of cases, as recorded cases are likely an under-estimate due to the large extent of under-reporting of leishmaniasis in the region.

Source: Postigo, 2010 and Alvar et al., 2012.

FIGURE 1: Geographical distribution of cutaneous leishmaniasis cases due to *L. infantum*, *L. major*, and *L. tropica* in North Africa



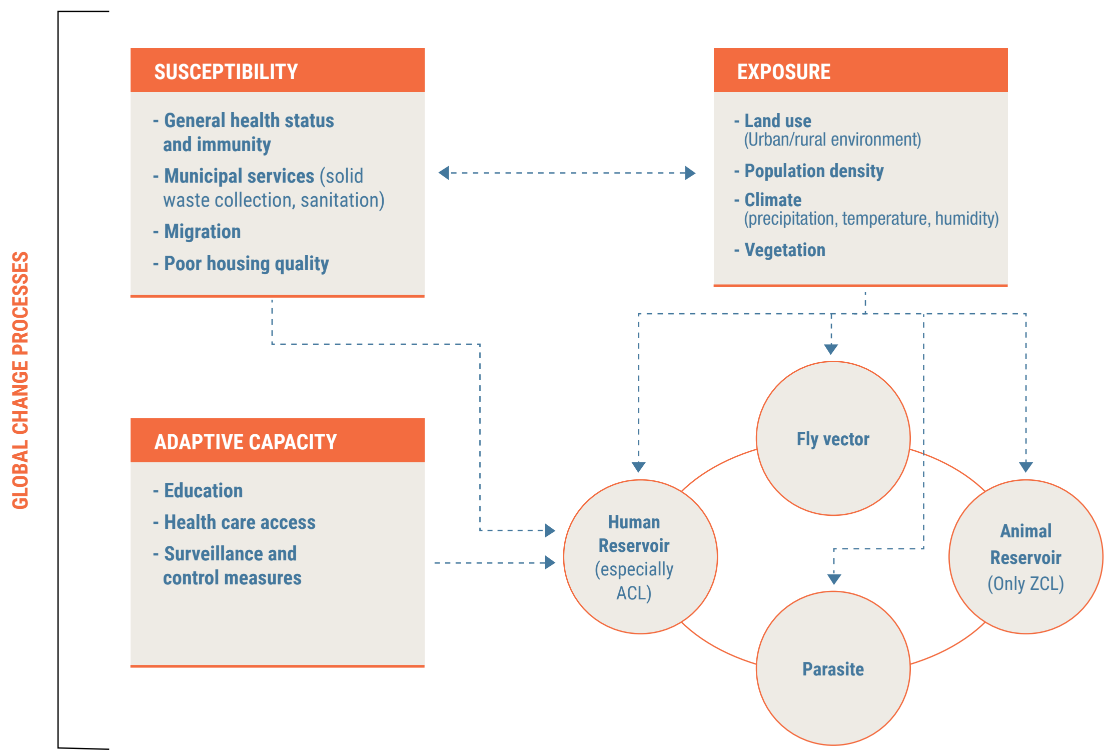
Source: Aoun and Bouratbine, 2014.

2.2 Conceptual WADI Framework

2.2.1 WADI framework components

The general WADI conceptual framework developed for leishmaniasis is presented in Figure 2. Bias-corrected regionally downscaled future climate projections for the MENA domain developed as part of RICCAR were used in the case study. For other components of vulnerability, the most current data available was used due to limited availability of future socio-economic and land use projections. While the aim of the WADI approach is to identify areas that are conducive to disease transmission, this does not identify specific areas of infection due to the focal nature of the vector and pathogen.[20] For instance, the reservoir host is distributed in sandy desert areas, but is specifically found in vegetated areas such as near edges of wadis (intermittent streams).

FIGURE 2: Conceptual WADI framework illustrating linkages between the human, vector, parasite and animal reservoir components of the leishmaniasis disease cycle



Note: Dashed lines indicate connections between exposure, susceptibility, adaptive capacity and components of the disease cycle.

2.2.2 Exposure indicators

Exposure to leishmaniasis is strongly influenced by environmental conditions which constrain the range of the insect vectors as well as host animals and disease agents and thus affect where the disease is transmitted. Climate change is reducing the number of cold days and nights and raising minimum temperatures,[21] which has important implications for diseases like leishmaniasis that is constrained by temperature. At the same time, higher maximum temperatures in some areas will likely be detrimental to leishmaniasis vectors, and increasingly dry conditions are less favourable for *P. obesus* hosts which prefer desert areas with vegetation and relatively wetter soils.[22] Based on the framework described previously and the availability of relevant datasets, specific thresholds were used to identify areas of exposure to leishmaniasis. They are presented in Table 2.

TABLE 2: Components and indicators for the exposure to leishmaniasis

Component	Threshold or Indicator	Rationale	Data source
Temperature	Vector temperature limits for *P.papatsi*: • T_{max} > 40°C= 0 (no exposure) • T_{min} < 10°C= 0 (no exposure) • T_{ave} 25-28°C= 1; linear increase from or decrease to 10°C /40°C= 0	Minimum temperature is critical for the suppression of leishmaniasis, as this limits the vector and reservoir during the winter months (Bounoua et al., 2013; Toumi et al., 2012). While high temperatures also limit sandflies, the vector's nocturnal activity may reduce this effect. After 28°C, offspring population declines during reproductive period (Kasap and Alten, 2006).	RICCAR bias-corrected RCM
Relative humidity	Vector humidity limits • Relative humidity (%) ranging from 0 to 1 • 0% humidity= 0 • 100% humidity= 1	Humid conditions favour vector survival and reproduction. Humidity has been found to be a greater predictor than rainfall (Toumi et al., 2012). Humid vegetated soils are also preferable areas for the dominant rodent host.	RICCAR raw RCM (ESGF, 2016)
Rainfall (Humidity used instead if available to avoid redundancy)	Linear increase from 0 to 1, with maximum exposure at 40 mm, decrease above 40 mm.	Rainfall increases the density of vegetation (chenopods) that constitutes the food of the reservoir animal in the zoonotic form but excess rain causes flooding which damages rodent burrows (Fichet-Calvet et al., 2000; Toumi et al., 2012).	RICCAR bias-corrected RCM
Land use (ZCL)	• Bare soil cover with minimal vegetation= 1 • Shrubs, grassland, cropland= 0.25 • Forest area= 0	The rodent reservoir host is found in desert or semi-desert regions with sandy soils. Within these sandy areas the dominant reservoir host is found near the vegetation cover (chenopods) it requires for food. Environmental changes such as desertification or development of water resource management projects (which creates wet areas that change humidity and soil moisture) may increase exposure (Salah et al., 2007; WHO, 2017a).	Global Land Cover-SHARE (Latham et al., 2014)
Population density (ACL)	• >200 persons/km^2 = 1 • 100-200 persons/km^2 = 0.75 • 50 – 100 persons/km^2 = 50 • 25 – 50 persons/km^2 = 0.25 • <25 persons/km^2 = 0	Anthroponotic cutaneous Leishmaniasis relies on humans as reservoirs for the parasite (WHO, 2017a) with increasing exposure in denser areas. Urbanisation may favour increased exposure.	Gridded Population of the World (CIESIN, 2005)

Note: Components in grey shading were not considered due to limited data availability or to reduce redundancy between indicators.

2.2.3 Susceptibility and adaptive capacity indicators

Susceptibility to leishmaniasis is determined by a range of factors particularly related to socio-economic status, including housing quality and sanitary conditions which can increase sandfly breeding and resting sites, and provide easier access to human hosts.[23] In addition, epidemics of leishmaniasis are frequently associated with migration which brings non-immune people into areas with transmission cycles, a situation particularly relevant in the MENA region. Poor health status can increase susceptibility to infection with many different NTDs, including leishmaniasis.

Adaptive capacity comprises prevention and control interventions to stop the transmission of the disease. This may include a combination of intervention strategies including adequate healthcare access and education as well as health promotion activities to ensure people recognize an infection quickly and seek treatment. Surveillance and reporting systems are also important to prepare for climate change impacts on transmission patterns, as they provide evidence for public health authorities. Based on the WADI framework for leishmaniasis, the following indicators were used to assess susceptibility (Table 3) and adaptive capacity (Table 4) to the disease.

TABLE 3: Components and indicators for the susceptibility to leishmaniasis

Component	Indicator	Rationale	Data source/ Notes
Poor housing quality	% Households with poor housing quality	May increase sandfly breeding and resting sites, and increases proximity to humans (Desjeux, 2005; WHO, 2017a).	Not available
Poor sanitary conditions/waste management	% Households not connected to a public or private sewage disposal system	Poor sanitary conditions may increase sandfly breeding and resting sites (Desjeux, 2005; WHO, 2017a).	General Census of Population and Housing 2004 (Morocco Statistics Directorate, 2012)
Migration/ Displacement	% Migrated in last 5 years from different administrative area or country	Migration to urban areas provides a high density of susceptible humans (Dujardin, 2006; WHO, 2017a).	General Census of Population and Housing 2004 (Morocco Statistics Directorate, 2012)
Undernutrition/ HIV/Immune status	% Population with malnutrition/ undernutrition	Immune status is an important factor for re-emergence and spread of leishmaniasis (Dujardin, 2006; WHO, 2017a).	Not available

Note: Components in grey shading were not considered due to limited data availability or to reduce redundancy between indicators.

The *P. papatasi* sandfly, vector of *Leishmania* parasites. Source: Center for Disease Control and Prevention.

Lesions due to infection with *L. major*. Source: Aoun and Bouratbine, 2014.

TABLE 4: Components and indicators for the adaptive capacity to leishmaniasis

Component	Indicator	Rationale	Data source/ Notes
Healthcare access	Distance to healthcare clinic or facility	Early detection and treatment reduces the severity of a case (Postigo, 2010). Treatment failure is a risk factor for the re-emergence and spread of leishmaniasis (Dujardin, 2006).	Not available
Surveillance	Use of surveillance/ reporting by local public health departments	Surveillance is needed to detect new foci and allow monitoring of spatial dynamics (Postigo, 2010). No global surveillance is conducted, nor tracking of environmental changes or other risk factors or their interactions.	Not available
Education	% Women completing secondary education	Education improves ability to understand health-related messages (WHO, 2017a). Women are often in charge of healthcare for their family.	General Census of Population and Housing 2004 (Morocco Statistics Directorate, 2012)
Vector control	Use of vector-control by local public health departments	Vector control reduces or interrupts transmission of disease by controlling sandflies, especially in domestic areas (WHO, 2017a). Indoor residual spraying is needed, but requires compliance (Postigo, 2010). Disruption of health systems (e.g. due to conflicts) impacts vector control and leads to higher sandfly density (Dujardin, 2006).	Not available

Note: Components in grey shading were not considered due to limited data availability or to reduce redundancy between indicators.

2.3 Results

The results of this assessment indicate that changes in climate may have an important impact on the range of leishmaniasis transmission in the Arab region. Like many vector-borne diseases, leishmaniasis incidence displays a strong seasonality due to the influence of climate variables. In the study area, minimum temperatures historically drop below the sandfly vector's survival thresholds (10°C) during colder months, limiting disease transmission.

Based on exposure projections, results indicate that warmer temperatures during colder months could extend the period of suitability for disease transmission due to minimum temperatures occurring less frequently below the sandfly survival threshold. As shown in Figure 3 for November, areas indicating no exposure (in white) become more and more limited by the end of the century in particular for RCP 8.5. However, in some areas exposure may be reduced where maximum temperatures exceed 40°C for longer periods, such as in summer months (Figure 4), due to the upper end of the sandfly survival range. Eventhough the extent of areas characterized by temperatures exceeding 40°C will expand, many of these areas are in sparsely inhabited regions and therefore will have less impact on human populations. In addition to temperature conditions, vegetation for the animal host may decrease in some areas with decreasing moisture availability associated with changes in humidity. Overall, the results of this case study show that climate change may have important impacts on the transmission of leishmaniasis in endemic areas of western North Africa, particularly by extending the length of the transmission season.

Climate conditions are only one aspect of exposure and overall vulnerability. Within exposed areas, zoonotic cutaneous leishmaniasis is characterized by focal outbreaks, whereby foci occur in areas with suitable vegetation for the rodent reservoir's host in proximity to human populations. Foci may also occur where susceptibility is higher due factors such as poor housing quality and sanitary conditions that provide breeding sites for the vector or high rates of in-migration that increases the non-immune population. Figure 5 indicates that many areas that are exposed to zoonotic cutaneous leishmaniasis in Morocco are more susceptible and have lower adaptive capacity compared with other parts of the country. This means that public health authorities can target resources to implement vector control activities in order to decrease exposure during longer seasons of transmission, as well as improving capacity of the population to cope with outbreaks.

FIGURE 3: Historical and projected exposure to leishmaniasis in North Africa in November

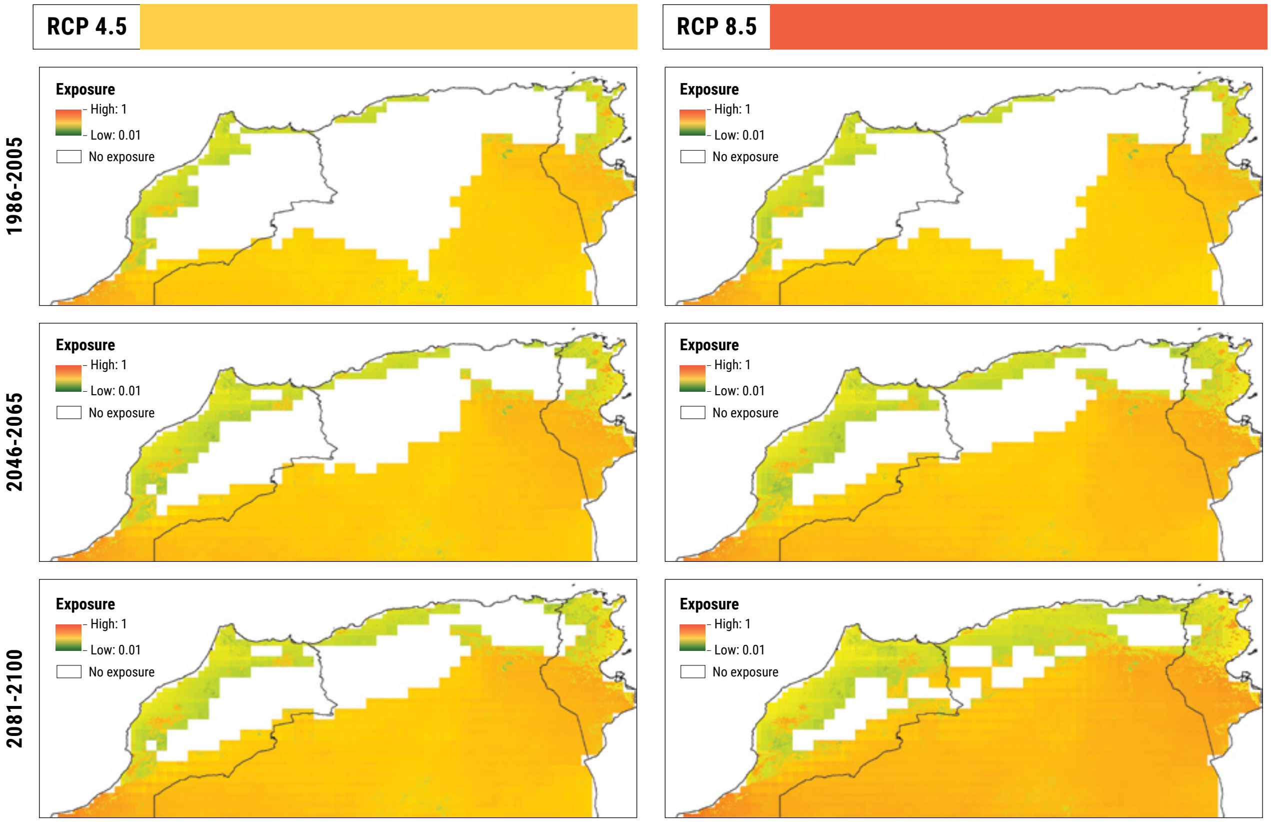


FIGURE 4: Historical and projected exposure to leishmaniasis in North Africa in June

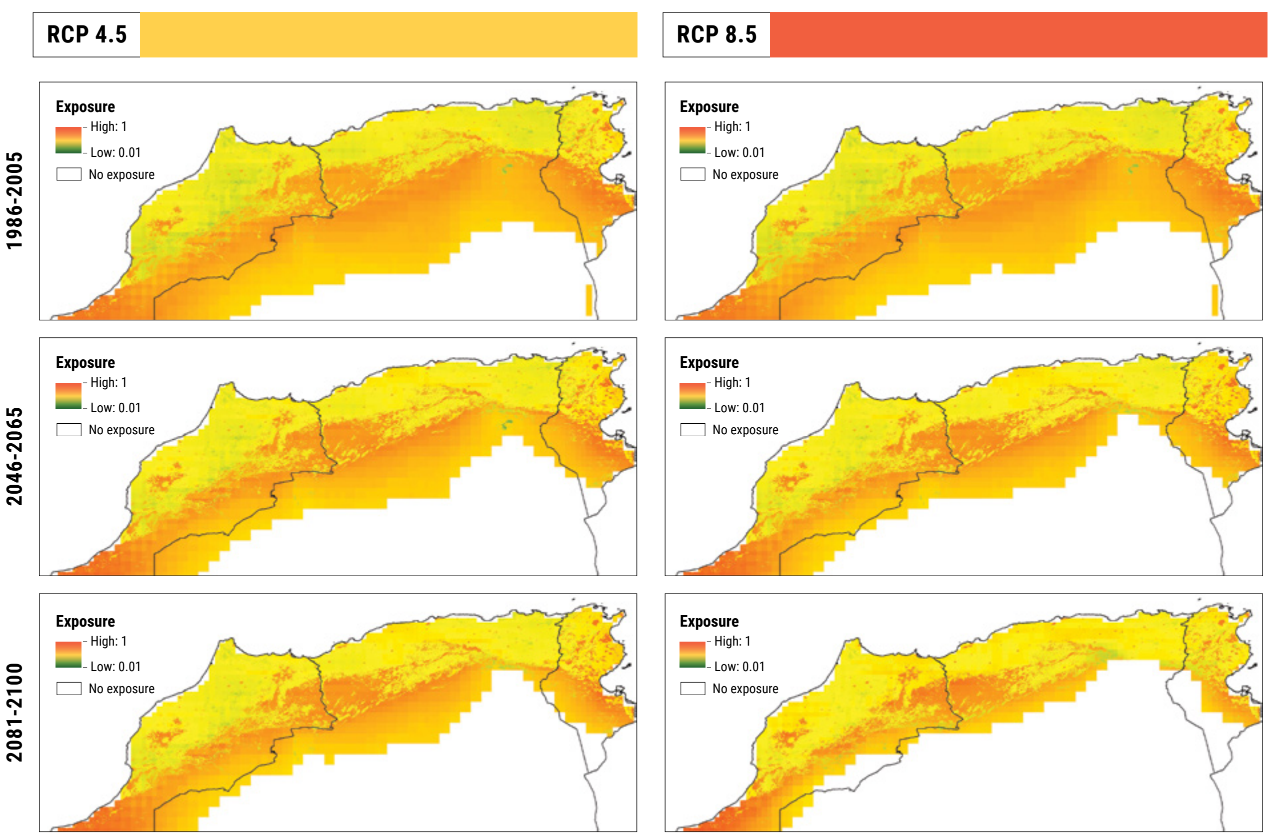
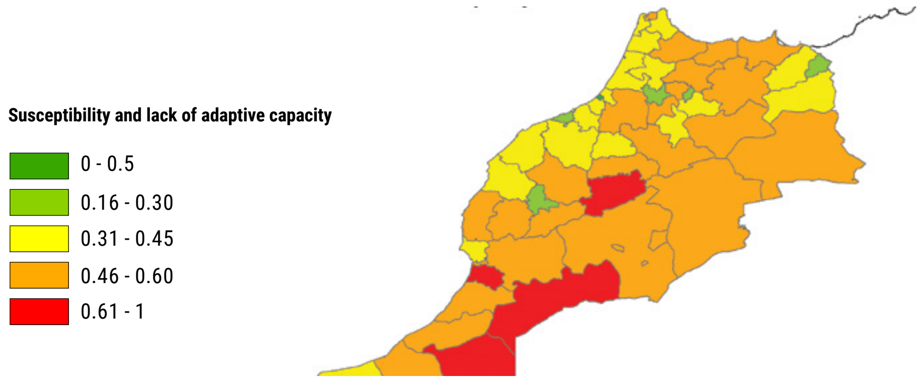


FIGURE 5: Susceptibility and lack of adaptive capacity to leishmaniasis in Morocco



3 SCHISTOSOMIASIS IN EGYPT

3.1 Background on Schistosomiasis

Schistosomiasis is a parasitic disease resulting from contact with contaminated fresh water sources. The disease is transmitted by blood flukes known as schistosomes which have freshwater snail hosts. There are approximately 250 million people infected worldwide, leading to a large burden of chronic morbidity. Due to the enduring impacts of childhood schistosomiasis infection, up to 70 million Disability-Adjusted Life Years (DALYs) are lost globally, exceeding that of malaria or tuberculosis according to some estimates. The disease disproportionately affects the poorest people in endemic areas, including those without access to safe water and sanitation, and those with water-based livelihoods such as fishing and rice farming.[24] In the MENA region, schistosomiasis is the second most prevalent NTD with an estimated 12.7 million cases. The highest prevalence is reported in Egypt where *S.mansoni*, which causes intestinal schistosomiasis, is endemic in northern regions, and was thus chosen for this case study (Table 5).[25]

Recent advances have been made in eliminating a range of endemic NTDs in the region, particularly in the case of schistosomiasis in Egypt where mass drug administration has led to the near-elimination of the other form of schistosomiasis, *S. haematobium*, which can cause bladder cancer in advanced cases.[26] While efforts to control schistosomiasis in Egypt have been successful, certain communities in the Nile Delta with high prevalence rates sustain transmission of the disease.[27] In addition, although treatment is used to combat the disease, it is important to understand the effect of climate change on disease incidence, re-emergence potential, and control efforts over the long-term so that public health officials can respond and build capacity to cope and adapt to the projected impacts of climate change.

TABLE 5: Schistosomiasis incidence in selected Arab States

Country	Estimated cases per year (prevalence)
Algeria	2 million
Egypt	7 million (10%)
Iraq	<0.1 million (<1%)
Morocco	<0.1 million (<1%)
Saudi Arabia	<0.1 million (<1%)
Sudan	5 million (15%)
Syria	<0.1 million (<1%)
Yemen	3 million (3%)

Source: Hotez et al., 2012.

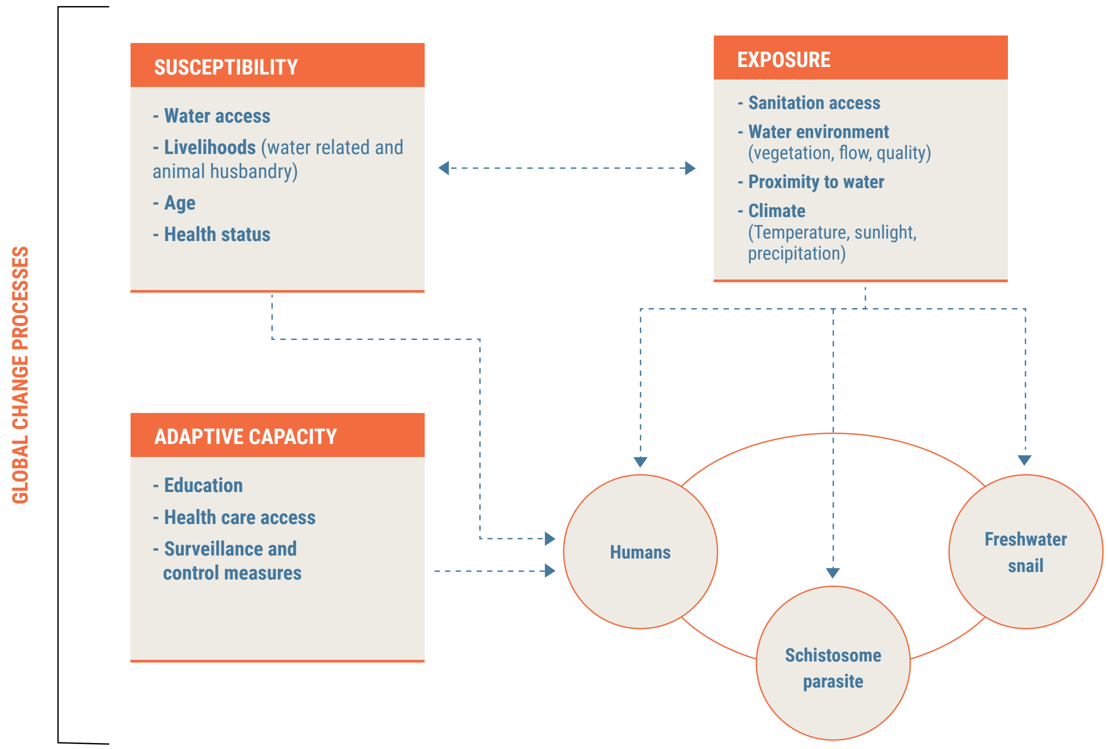
The *Biomphalaria* sp. aquatic snails, hosts for *S. haematobium* and *S. mansoni*.
Source: Lewis et al., 2008.

3.2 Conceptual WADI Framework

3.2.1 WADI framework components

The WADI framework developed for schistosomiasis is presented in Figure 6.

FIGURE 6: Conceptual WADI framework illustrating linkages between the human, schistosome parasite and freshwater snail components of the schistosomiasis disease cycle



Note: Dashed lines indicate connections between exposure, susceptibility, adaptive capacity and components of the disease cycle.

3.2.2 Exposure indicators

Exposure to schistosomiasis is strongly influenced by environmental factors, including climate conditions, availability of water bodies with suitable habitat to support freshwater snail populations and lack of safe sanitation access which propagates the cycle of schistosome eggs entering water bodies. Higher temperatures due to climate change are expected to impact the schistosomiasis life cycle, affecting the prevalence and severity of the disease.[28] In addition, proximity to water resources increases exposure to schistosomiasis.

The thresholds/indicators used to identify areas of exposure to schistosomiasis are presented in Table 6 and draw from freely available datasets. While these components constrain areas that are suitable for schistosome parasites and host snails, within these areas schistosomiasis is characterized by focal distributions, reflecting the multiple local factors that determine habitat suitability and transmission. In Egypt, although near elimination has been achieved in many areas, control programs must be sustained for 10-20 years to insure full elimination,[29] a process which could be disrupted by social or environmental changes in the region.

TABLE 6: Components and indicators for the exposure to schistosomiasis

Component	Threshold or Indicator	Rationale	Data source/ Notes
Temperature	• T_{ave} 19°C infection risk= 1 • Linear increase/decrease between schistosome infection risk temperature limits : < T_{ave} 15°C= 0 exposure >T_{ave} 30°C= 0 exposure	Temperature impacts both snail and schistosome survival (Sturrock, 2001). While snails may survive at lower temperatures than schistosome parasites, temperature limits infection risk (McCreesh and Booth, 2014)	RICCAR Bias-corrected RCM
Rainfall	Not enough evidence available on the direction of trend in the Arab region	Rainfall supports survival of eggs on land and carries eggs to freshwater bodies (Kabatereine et al., 2004), however excessive rain can disrupt snail habitats and limits vegetation available. Irrigation may be used where there is little rainfall, which also increases exposure. The relationship between exposure and rainfall is thus difficult to specify.	RICCAR Bias-corrected RCM could be used
Snail habitat (water body)	• Slow flowing water with vegetation= 1 • Irrigated land= 1 • Water resources projects= 1 • Bare land= 0	Still to gentle flowing water with low turbidity and vegetation is preferred by host snails (water velocities lower than 0.7 m/s). Moderately polluted water with faecal and/or organic plant material supports snail population development. High sunlight shortens egg survival on land, but moderate sunlight supports vegetation growth in water bodies that provide snail habitat.	Not available
Proximity to water bodies	Buffer around water sources: • <5 km= 1 • 5-10 km= 0.75 • 10-20 km= 0.25 • >20 km= 0	Water-contact results in exposure to the disease (Handzel et al., 2003) and increasing proximity to an infected water body increases water contacts. In Egypt, land is irrigated using ditches and channels diverted from the Nile, so exposure areas extend outward from the river, most within 10 km, and some up to 20 km.	Buffers around water bodies were created using inland water bodies (National Imagery and Mapping Agency, 2000)
Access to sanitation	% population with public sewage network connection or private system (septic tank)	Schistosome eggs are released into the environment in feces or urine, which contributes to propagating the disease life cycle (WHO, 2017b).	2006 Census Data for Egypt (CAPMAS, 2015)

Note: Components in grey shading were not considered due to limited data availability or to reduce redundancy between indicators.

3.2.3 Susceptibility and adaptive capacity indicators

Schistosomiasis is strongly influenced by social determinants such as water-based livelihoods, marginalization of vulnerable groups or poor access to water, all of which leads to greater water contacts. Susceptibility to schistosomiasis is greatest in poor and rural communities, particularly agricultural and fishing populations.

Building adaptive capacity to prevent and control schistosomiasis in the context of changing social and environmental conditions relies on treatment of exposed and susceptible population groups, as well as ensuring safe water access, controlling snail populations, and continued monitoring and surveillance to ensure avoid re-emergence or emergence in new areas. Based on the WADI framework for the disease, the indicators presented in Table 7 and Table 8 were used to identify areas of susceptibility and adaptive capacity to schistosomiasis, respectively.

TABLE 7: Components and indicators for the susceptibility to schistosomiasis

Component	Indicator	Rationale	Data source
Access to water resources (in rural areas)	% Population with improved water source	Water contact resulting from the need to collect water in contaminated areas can result in schistosome larvae penetrating human skin which causes infection (WHO, 2017b).	2006 Census Data for Egypt (CAPMAS, 2015)
Water-related livelihoods	% Population engaged in water-based livelihoods (e.g. fishing, irrigating)	Water contact resulting from water-based livelihoods, such as fishing in contaminated areas can result in schistosome larvae penetrating human skin which causes infection (Dunne et al., 2006; WHO, 2017b).	2006 Census Data for Egypt (CAPMAS, 2015)
Age	% Population under age 15	Children are more heavily infected (Dunne et al., 2006) and experience more serious health impacts due to schistosomiasis infection.	2006 Census Data for Egypt (CAPMAS, 2015)
Health status	% Under-weight in children under age 5	Immune status, e.g. HIV/AIDS, under-nutrition, and other underlying health concerns increase susceptibility.	Egypt Ministry of State for Economic Development, 2008

TABLE 8: Components and indicators for the adaptive capacity to schistosomiasis

Component	Indicator	Rationale	Data source/ Notes
Healthcare access	Health units/100,000 persons	Treatment is straightforward and reduces further transmission of the disease (WHO, 2017b).	MOHP, 2008
Education	% Females completing secondary education	Improves ability to understand health messages such as hygiene practices, treatment availability and ways of reducing re-infection through greater adoption of sanitation facilities (O'Loughlin et al., 2006). Women are often responsible for their family's healthcare.	2006 Census Data for Egypt (CAPMAS, 2015)
Surveillance and reporting	Use of surveillance/ reporting by local public health departments	Surveillance is needed to detect cases and the presence of host snails in water bodies to develop health promotion strategies.	Not available
Schistosomiasis control areas (MDA and vector control)	Use of MDA and vector control by local public health departments to treat people and remove snails	Snail removal or management of natural areas to reduce snail habitat availability is used in some areas (Rollinson et al., 2013).	Not available

Note: Components in grey shading were not considered due to limited data availability or to reduce redundancy between indicators.

3.3 Results

The results of this assessment indicate that changes in climate may influence the seasonal pattern of schistosomiasis transmission in Egypt. Schistosomiasis transmission in the region occurs on a seasonal basis, with most cases occurring during the warmer summer months, and particularly in the Nile Delta with the intensive water contacts due to the prevalence of water-based livelihoods. While transmission is limited in colder months, the results of this case study suggest that increasing temperatures projected in RCP 4.5 and RCP 8.5 at mid- and end- of century will create conditions that increase infection risk during winter months. Figure 7 highlights historical exposure in December during the winter, a season where fewer cases currently occur compared to exposure at mid- and end- of century. Areas in white indicate conditions of no exposure.

FIGURE 7: Historical and projected exposure to schistosomiasis in Egypt in December

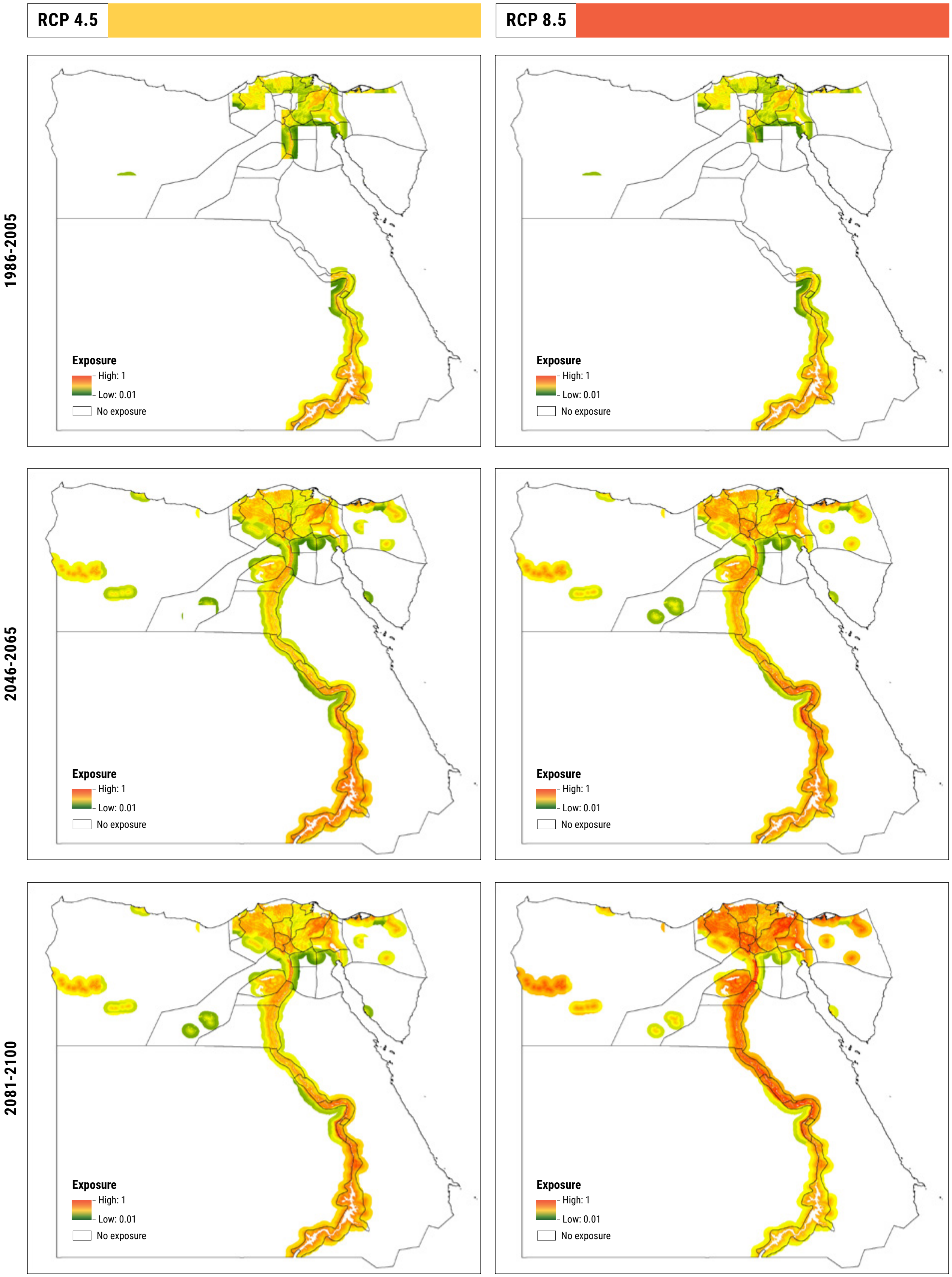
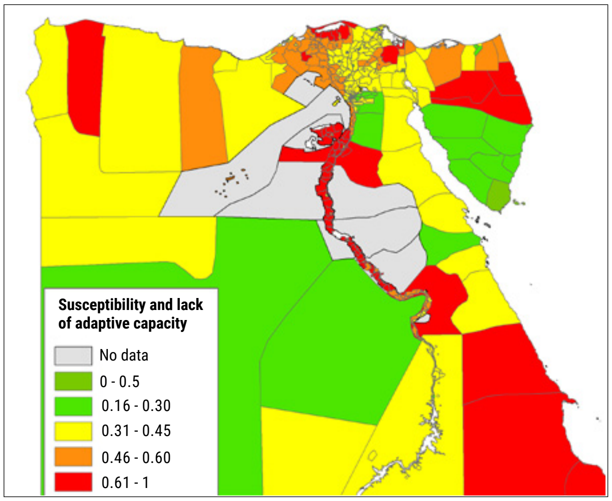


FIGURE 8: Susceptibility and lack of adaptive capacity to schistosomiasis in Egypt



Northern Nile Delta, Egypt, 2015. Source: Ihab Jnad.

Because these changes in temperature occur near thresholds for schistosome infection risk, small increases can make a considerable difference. The survival of *B. alexandrina* snails is likely to occur most of the year,[30] but in colder months they are currently uninfected. In addition, other species of snail, such as *B. pfeifferi*, the most widespread intermediate host of *S. mansoni* in Africa, survive at slightly warmer temperatures than *B. alexandrina*, so could become established in greater numbers in the area in warmer conditions.[31] These findings have implications for public health authorities who currently undertake vector control activities during the warmer months when most people become infected. Changing climate conditions could also impact the success treatment measures such as de-worming programmes if they are timed for warmer periods.

It is also important to note that schistosomiasis transmission may be impacted by increasing temperatures that surpass temperature limits for infection risk, as well as the upper survival limit of *B. alexandrina* snails during summer months. This could lead to decreased transmission during this period, so carefully monitoring seasonal trends is important to understand how climate change is impacting the disease.

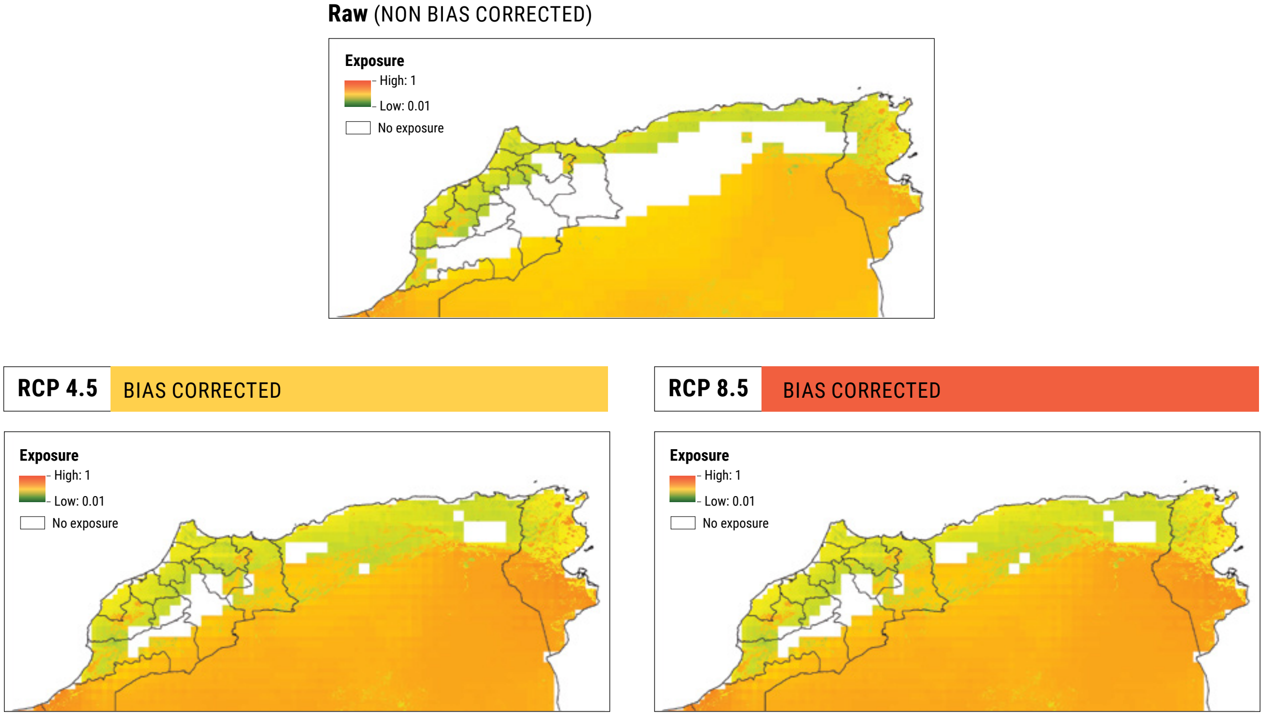
Importantly, changes in exposure are projected to occur in areas in the Nile Delta where the population currently experiences higher susceptibility due to water-based livelihoods and limited sewage connections (Figure 8). In these areas climate change could have a larger impact on the burden of disease by increasing the length of the transmission season. In addition to climate change, other positive or negative social and ecological changes in the Arab region such as increasing access to sanitation, land degradation, or conflicts which disrupt control and elimination efforts could have important impacts on the disease cycle.

4 COMPARISON OF RAW AND BIAS-CORRECTED RESULTS

4.1 Exposure to Leishmaniasis

In the case of leishmaniasis, bias-corrected data indicates that the winter period when transmission is reduced starts at a later date and ends earlier, due to warmer conditions indicated by bias-corrected data. This can be observed in Figure 9 where regions indicating low or no exposure for the month of October, which is towards the end of the transmission season, are larger in the case of raw (non bias corrected) data outputs. As can be seen from the figure, areas without exposure conditions are greater for the raw data due to cooler temperatures.

FIGURE 9: Comparison of exposure to leishmaniasis in October for the reference period 1986-2005 using raw RCMs and bias-corrected RCMs



4.2 Temperature Thresholds for Schistosomiasis

Temperature thresholds that determine snail survival modeled by McCreesh and Booth (2014) were initially used as part as the exposure layer for schistosomiasis which indicated that during colder months such as December, survival of snails is reduced. However, the upwards shift in temperature found in the bias-corrected data occurs very close to this survival threshold, significantly changing the initial results. As shown in Figure 10 which displays temperature in December (when transmission is historically lower), bias-corrected results indicate more suitable temperature conditions for snail survival for both time periods. Bias-corrected outputs suggest that temperature limitations on snail survival occur over a shorter period during the year than initially found.

Since transmission is known to be reduced in the winter months, an indicator of infection risk that is linked to snail infection with the schistosome parasite was used, as modeled by McCreesh and Booth (2014). Infection risk occurs at a higher temperature threshold than snail survival, and as previously shown in Figure 7, infection risk remains low during the historical winter period.

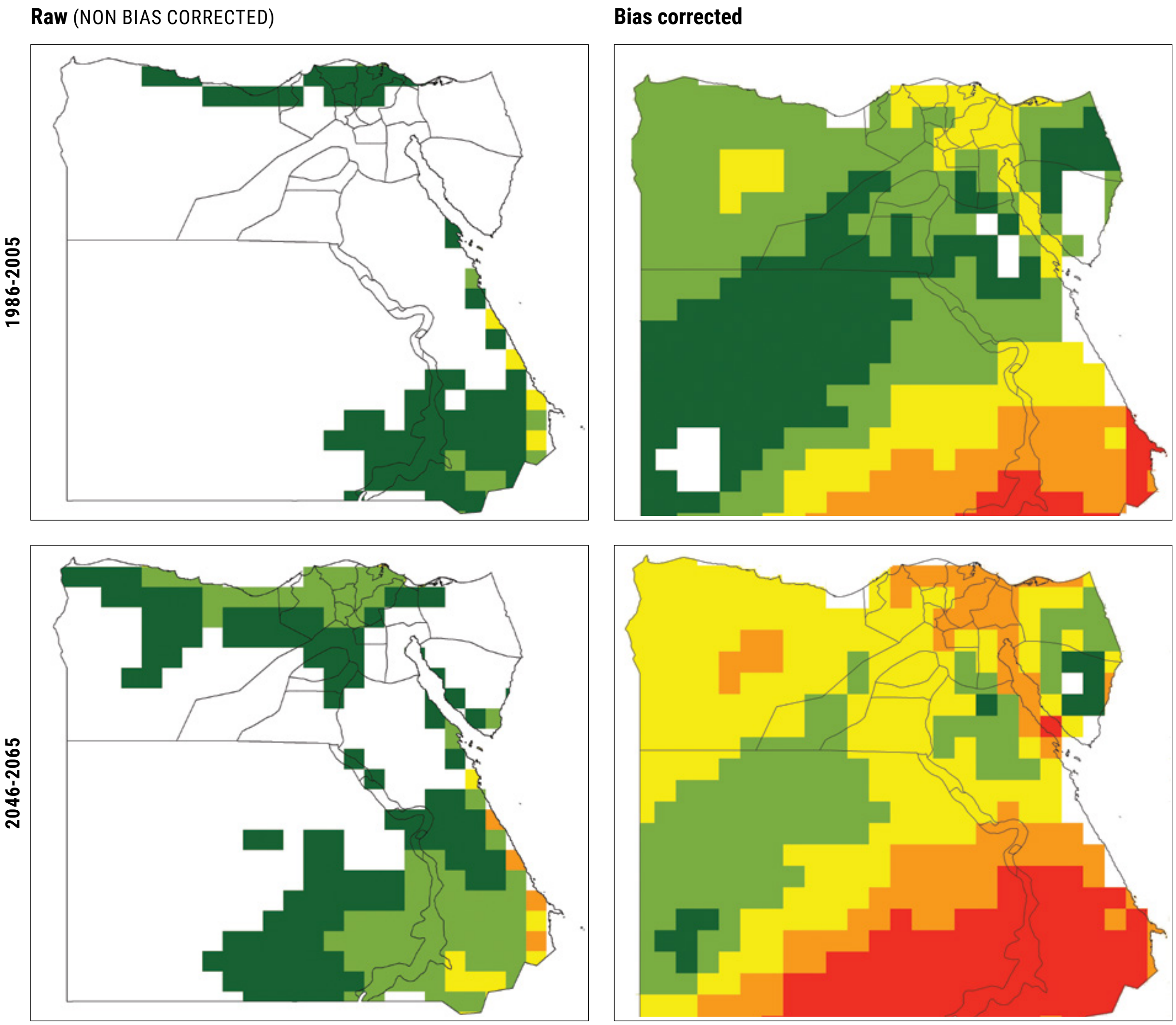
4.3 Conclusion

As indicated by comparison results, due to a cold-bias in the climate data, bias-correction had a significant impact on the results, particularly in the case of schistosomiasis.

The sensitivity of many infectious diseases to specific temperature thresholds (which may mean the difference for vector survival) highlights the impact that a bias-correction procedure can have on results, and the importance of considering appropriate approaches for bias-correction in health-focused studies where this processing step is not always applied.

FIGURE 10: Comparison of the temperature indicator used for schistosomiasis exposure for different time periods in December (RCP 4.5) using raw and bias-corrected RCMs

RCP 4.5



5 IMPLICATIONS AND CONCLUSIONS

5.1 Implications for Public Health

Beyond the serious health burden associated with NTDs, these chronic infections can trap people in a cycle of poverty and are often associated with social stigma. In this assessment, the potential impacts of climate change on two important NTDs in the Arab region were highlighted. Case studies on leishmaniasis and schistosomiasis indicate that climate change may impact the seasonal duration of disease transmission.

In the case of leishmaniasis, reactivation of old foci as well as expansion beyond its natural eco-region has been observed in Libya, Algeria, Tunisia, and Morocco.[32] In Tunisia, recent research has identified a trend of decreasing duration of the cold season and increasing warm season duration, which may be linked to this expansion.[33] While results of this study indicate that higher projected temperatures will reduce exposure in some areas, these are typically less inhabited regions. On the other hand, increasing minimum temperatures have the potential to increase exposure, which could increase the number of cases in areas that are susceptible to disease transmission. These findings have implications for vector control, surveillance and awareness building activities carried out by public authorities.

To be able to adapt to the potential climate change impacts on health, public authorities require better knowledge of how to integrate this information into their existing short and long-term plans. In particular, developing capacity of public health users of climate information is needed in order to address uncertainty in the case of different projected trends. Stronger surveillance systems are also needed to be able to adapt to the changes in transmission season and range of expansion. Efficiently collecting and sharing information on reported cases can improve the overall capacity of healthcare systems to respond to changes in transmission patterns as well. In addition, there is limited evidence on climate change impacts on health in the Arab region compared with other regions, so further research is needed. This will improve understanding of how climate change processes interact with regional environmental and social contexts to improve decision-making.

The role of climate change is not simply limited to changes in climate variables. Extreme events associated with climate change may also impact the distribution of NTDs and efforts to develop sustainable control strategies. Moreover, these climate change impacts must be considered within the context of concurrent social and other environmental changes, such as large human and animal migrations, conflict and associated breakdowns in public health systems, and socio-economic development.[34] For instance, reduced use of camels for transportation has removed the only competition for vegetation required by leishmaniasis rodent reservoirs, allowing the rodent population to grow. In addition, desertification and water resource development projects to address increasing water scarcity have played a role in supporting the transmission of NTDs such as leishmaniasis, as they can increase exposure to the disease.[35] In addition, migration of people within their country or to other part of the region can lead to large outbreaks in new areas. These changes can interact with changes to climate variables to exacerbate exposure and susceptibility conditions.

5.2 Implications for Gender and Social Equity

The burden of neglected tropical diseases is higher in poor and marginalized communities,[36] indicating a disproportionate threat due to changing climate conditions.

In the case of leishmaniasis, the disease has been found to present a greater threat to the health and socioeconomic status of women.[37] In Tunisia, women involved in agriculture have higher vulnerability as they have an increased exposure due to irrigation activities and higher sensitivity to the negative social implications of the disease.[38] In Yemen, incidence of leishmaniasis was found to be higher among rural children and female populations, which may be due to their work in agriculture and animal care, as well as water collection when they may be exposed to sand fly bites.[39] In addition, women's limited access to financial resources may reduce access to healthcare in order to receive treatment for the disease. In the case of cutaneous leishmaniasis, which can cause disfiguring scars, this can have a severe impact on women's psychological wellbeing and quality of life due to social stigmatization.

In the case of schistosomiasis, changes in exposure to the disease are projected to occur in areas in the Nile Delta where the population currently experiences higher susceptibility. As this is a water-associated disease, there are particular implications for women and girls who often spend large amounts of time doing water, sanitation and hygiene-related tasks, as well as caring for sick members of their families. While this assessment focused on exposure conditions, more in-depth analyses of vulnerability could improve targeting of responses to more disproportionately impacted communities or groups of people.

5.3 Limitations

Several limitations should be considered regarding this case study. This assessment applied regional climate projections, however disease incidence is characterized by extremely focal outbreaks within exposed areas. The results should not be taken as predictive of future prevalence of schistosomiasis or leishmaniasis, but as indicative of areas where projected changes in climate may influence the suitable conditions for transmission. Not all possible indicators are considered in the case studies, as there is limited evidence on some linkages in the Arab region, or because datasets are unavailable. For instance, in the case of schistosomiasis and given the available indicators considered in the exposure assessment, results show that disease exposure covers the course of the Nile River, while the actual disease prevalence is more restricted to the lower Nile.

Also, while increased precipitation may increase schistosomiasis transmission by washing schistosome eggs into water bodies, too much water can disturb snails. Conversely, lack of rainfall can increase irrigation activities and increase exposure, so without clear evidence on the direction of this trend, rainfall is left out of the case study. In addition, slow water currents and abundant vegetation are preferred habitat for the snail host of *S.mansoni* and would improve the exposure layer, but limited information was obtained on these conditions.

In addition, the land-cover class 'bare soil' from the GLC-SHARE global land-cover dataset is used to identify sandy or salt flat areas that contain sparse vegetation suitable for the leishmaniasis animal reservoir.[40] However, a more detailed classification could be done to better identify specific vegetated areas, and their seasonal changes.[41] For instance, areas where humidity is increased due irrigation can create more favourable conditions for the sandy vector. In addition, due to limited attention in the literature and the complex ecology of leishmaniasis, more research is needed to understand the impact of interactions between different risk factors.

Many countries in the Arab region have experienced rapid changes, and thus face particular challenges with monitoring NTD outbreaks such as leishmaniasis and maintaining accurate case records. For instance, in conflict areas health surveillance data is out-dated and is often not being collected due to break-downs in healthcare systems. Transmission may increase due to this reduced capacity to control certain diseases, however only estimates can be made and this means that validating exposure assessments with case data is challenging. While not the focus of this study, limited data was freely available on indicators of susceptibility and adaptive capacity which highlights data gaps that could improve vulnerability assessments. In addition, recent information was not available in many cases, which is particularly critical due the changing social and ecological characteristics in some regions.

5.4 Conclusions

Case studies on leishmaniasis and schistosomiasis indicate that climate change could impact the geographical extent and duration of disease transmission. In particular, increasing minimum temperatures have the potential to extend the seasonal period of exposure of both diseases. While higher projected temperatures will reduce exposure in some areas, these are typically less inhabited regions. These results have important implications for public health authorities working to control NTDs in the Arab region. Greater exposure conditions are most critical in areas that also have higher susceptibility and lower adaptive capacity, and have serious implications to the health and socioeconomic status of women. In particular, women working in agriculture face greater vulnerability to leishmaniasis as they may be exposed to sand fly bites during this work, while also having limited coping capacity such as limited access to financial resources for healthcare. Understanding these trends can help target disproportionately impacted communities and marginalized groups.

While significant progress is being made to control and eliminate many NTDs in the Arab region, there is a pressing need to consider how these efforts may be threatened by climate change. This is made challenging by poor surveillance and reporting capacities as well as a lack of information on incidence rates in many affected countries. In addition, climate change impacts must be considered in the context of other dynamic social and environmental changes occurring in the region. Despite these obstacles, further research to deepen understanding of the complex processes through which climate change will impact NTD dynamics is required in order to identify and adapt appropriate and equitable health promotion strategies.

ENDNOTES

1. Watts et al., 2015
2. Hotez, 2009
3. Hotez et al., 2012
4. Hewitson et al., 2014
5. Habib et al., 2010
6. Pal and Eltahir, 2016
7. Also referred to as wet-bulb temperature (Sherwood and Huber, 2010).
8. El-Fadel et al., 2012
9. Haines et al., 2014
10. Dickin et al., 2013
11. Birkmann et al., 2013
12. Alimi et al., 2016
13. McCreesh and Booth, 2014
14. De Sherbinin, 2014
15. Dickin et al., 2013
16. Pigott et al., 2014; WHO, 2017a
17. Alvar et al., 2012
18. Kedzierski, 2010
19. Postigo, 2010
20. Cross et al., 1996
21. IPCC, 2013
22. Fichet-Calvet et al., 2000
23. WHO, 2017a
24. Hotez and Fenwick, 2009
25. Hotez et al., 2012
26. Salem et al., 2011
27. Elmorshedy et al., 2015
28. Mangal et al., 2008
29. Curtale et al., 2010
30. McCreesh and Booth, 2014
31. Ibid.
32. Aoun and Bouratbine, 2014
33. Boubaker and Chahed, 2011
34. Hotez et al., 2012
35. Boubaker and Chahed, 2011
36. Du et al., 2016
37. Al-Kamel, 2016a; Boubaker et al., 2011
38. Boubaker, 2016
39. Al-Kamel, 2016b
40. Latham et al., 2014
41. Boubaker, 2016

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