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Review

The effects of climate change on human health in Africa, a dermatologic perspective: a report from the International Society of Dermatology Climate Change Committee

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Abstract

Throughout much of the African continent, healthcare systems are already strained in their efforts to meet the needs of a growing population using limited resources. Climate change threatens to undermine many of the public health gains that have been made in this region in the last several decades via multiple mechanisms, including malnutrition secondary to drought-induced food insecurity, mass human displacement from newly uninhabitable areas, exacerbation of environmentally sensitive chronic diseases, and enhanced viability of pathogenic microbes and their vectors. We reviewed the literature describing the various direct and indirect effects of climate change on diseases with cutaneous manifestations in Africa. We included non-communicable diseases such as malignancies (non-melanoma skin cancers), inflammatory dermatoses (i.e. photosensitive dermatoses, atopic dermatitis), and trauma (skin injury), as well as communicable diseases and neglected tropical diseases. Physicians should be aware of the ways in which climate change threatens human health in low- and middle-income countries in general, and particularly in countries throughout Africa, the world's lowest-income and second most populous continent.

Introduction

Establishing and sustaining a healthy population requires access to clean air, safe water, and an adequate food supply, as well as a stable climate with tolerable temperatures and high biodiversity. Climate change has affected and will continue to affect temperature, air quality, water supply safety, extreme weather event frequency, and the proportion of land suitable for growing crops.[1] Worldwide, these effects will be experienced disproportionately by already-vulnerable populations that are the least responsible for producing the anthropogenic greenhouse gases that cause global warming.

The African continent has the lowest gross domestic product (GDP) per capita and accounts for less than 4% of global greenhouse gas emissions.[2] In sub-Saharan Africa (SSA), where the socioeconomic conditions are strongly linked to the climatic conditions, loss of healthy life years as a result of climate change is predicted to be up to 500 times greater than in Europe.[3]

By 2020, 85–250 million Africans are projected to experience increased water stress as a result of climate change, and crop yields from rain-fed agriculture may decrease by up to 50%.[4] Since 30–40% of Africa's GDP and about three quarters of its population rely on agricultural production as a primary income source, the economic consequences of this could be devastating.[2]

Given that most of the continent is in the tropical climate zone, sea level rise is expected to be higher than average, and there are at least three African coastal cities with populations over 8 million that may be severely affected.[2] According to the World Bank, as of 2019, the combination of erosion, flooding, and pollution have led to losses of over 3.8 billion United States Dollars (USD) annually, or 5.3% of the combined GDP of Benin, Côte d'Ivoire, Senegal, and Togo, four countries along the West African Coast.[5]

African nations will be forced to continue their development under these constraints, and at a high cost; the United Nations (U.N.) estimates climate change adaptation costs to Africa of

50 billion USD by the year 2050.[4] Furthermore, many low- and middle-income African nations are relatively ill-equipped to adapt to the demands of recent multinational agreements, such as the Paris Climate Accords of 2015, as a result of weakened and/or ineffective central governments, underdeveloped public health institutions, widespread poverty, and in some cases, ongoing armed conflict. As of 2018, only 55% of African countries met the International Health Regulation core requirements for preparedness for a multi-hazard public health emergency.[6]

Climate change is expected to negatively affect human health in Africa in myriad ways, via exacerbating malnutrition, contributing to poor air quality, polluted drinking water, altering the geographic range of infectious disease pathogens and vectors, and triggering mass human displacement.

We summarize the direct and indirect effects of climate change on diseases with cutaneous manifestations in this region. We also discuss the path forward and current actions being taken throughout Africa to combat these effects.

Methods

We performed a scoping review of articles available on PubMed using the following combination of search terms from three categories: (i) climate change, climate, global warming, temperature, dry, drought, rainfall; in combination with (ii) Africa and (iii) either "dermatology" or each of the following conditions: non-melanoma skin cancers, atopic dermatitis, photodermatoses, dermatoses associated with malnutrition, dengue fever, chikungunya, Zika, leishmaniasis, malaria, tuberculosis, human immunodeficiency virus (HIV), Ebolavirus, schistosomiasis, lymphatic filariasis, onchocerciasis, trypanosomiasis, mycetoma, chromoblastomycosis, buruli ulcer, leprosy, scabies, pediculosis, tungiasis, dermatophytosis, superficial fungal infections, and podoconiosis. We also searched the World Health Organization (WHO) and the United States Centers for Disease Control and Prevention (CDC) websites for further information on epidemiology and current geographical distributions. We abstracted the following data with regard to each of the neglected tropical diseases (NTDs): disease, vector species (if applicable), geographic distribution within Africa, climate sensitivity, and cutaneous manifestations.

Table 1 The effects of climate change on human health

Heat waves	Increased death, especially among vulnerable populations (children, elderly, patients taking anti-cholinergic medications, patients with disorders of cornification)
Ultraviolet radiation	Higher temperatures decrease UV protective behaviors Increased risk of non-melanoma skin cancers and cataracts
Poor air quality	Flares of atopic dermatitis, allergic conjunctivitis, asthma
Higher temperatures, changes in humidity and/or precipitation	Extreme weather events – drought, flooding, severe storms Altered pathogenic microbe and/or vector viability • Dengue virus • Chikungunya virus • Zika virus • Leishmaniasis • Malaria • Schistosomiasis
Extreme weather events (drought, flooding, wildfires, severe storms)	Mass human displacement as a result of inhospitable environments and/or armed conflict • Further armed conflict • Urban and/or refugee camp crowding • Armed conflict • Mental health effects • Spread of communicable infectious diseases ▪ Scabies and body lice infestations ▪ Tuberculosis ▪ Human Immunodeficiency Virus ▪ Ebolavirus Food and water supply insecurity • Malnutrition • Cholera and other diarrheal illnesses Injury • Burns • Lacerations and puncture wounds ▪ *Staphylococcal* and *Streptococcal* skin infections • Blunt trauma
Economic harms/poverty	Malnutrition Higher burden of Neglected Tropical Diseases

Direct effects of climate change on human health

The effects of climate change on human health are summarized in Table 1. Certain health effects can be linked directly to meteorological variables.

Extreme temperatures

Temperature extremes are associated with increased mortality.[7] An analysis conducted over 17 years in South Africa found that extreme temperature-related mortality accounted for 3.4% of deaths during that time period.[8] In three major cities in South Africa, every 1 °C rise in temperature was associated with a 1–2% increase in mortality in those over 65 years of age.[6] Patients who do not have the means to readily dissipate heat via eccrine sweating, including young children, the elderly, persons taking medications with anticholinergic effects, and patients with disorders of cornification, are particularly vulnerable to death during heat waves. Persons with outdoor occupations (including miners and agricultural workers) and those

living in low-cost housing structures are also at higher risk.[9] In 2017, an estimated 153 billion hours of labor were lost as a result of rising temperatures.[6] The WHO estimates that, if no climate change adaptation efforts are implemented, annual mortality from heat waves alone will be 38,000 in 2030 and 95,000 in 2050.[10] SSA is among the world regions expected to be most severely affected by heat waves.[10]

Ultraviolet radiation

Extreme temperature alters protective behaviors – for example, removal of clothing on a hot day – and may increase exposure to ultraviolet radiation (UVR).[11] Higher ambient UVR levels are associated with increased rates of nonmelanoma skin cancers.[11] Several photosensitive dermatoses, including polymorphous light eruption, chronic actinic dermatitis, and photoallergic contact dermatitis, are all driven by the degree of UVR exposure.

Pollution

Air pollution has become an increasingly severe problem in large African cities. Between 2010 and 2016, air pollution concentrations worsened in nearly 70% of major cities worldwide, especially in low- and middle-income countries.[6] In 2015, ambient air pollution contributed to an estimated 2.9 million premature deaths worldwide[6] and approximately 4% of deaths in South Africa.[9] Higher temperatures are associated with a rise in airborne allergens, which may exacerbate asthma, allergic rhinitis, allergic conjunctivitis, and atopic dermatitis.[11] Air pollutants have also been directly correlated with increased outpatient visits for atopic dermatitis flares.[12]

Skin injury

The skin is the organ system most vulnerable to direct injury in the setting of extreme weather events, such as severe flooding. Skin penetration from injury increases the risk of secondary bacterial infection acutely and can also lead to chronic morbidity. Increases in flooding probability are highest in East Africa.[13] An illustrative and devastating example occurred in March 2019, when Cyclone Idai caused severe flooding in Mozambique, Zimbabwe, and Malawi. This natural disaster affected approximately 3 million people, led to more than 1,000 deaths, displaced hundreds of thousands of people, and caused more than 2 billion USD in property damage.[14]

Indirect effects of climate change on human health

The indirect effects of climate change on human health are even more numerable. Alterations in temperature and precipitation affect food and water availability, increasing the risk of malnutrition and famine. Extreme weather events increase the likelihood of both armed conflict and mass human migration. Finally, variation in precipitation and surface freshwater availability affects the incidence of water- and vector-borne diseases.

Food insecurity and malnutrition

The influence of climate on food production and distribution is particularly important in low-income countries that depend largely on rain-fed agriculture to meet the nutritional needs of their population. Climate change-induced heat waves promote drought and desertification, which consumes previously fertile lands, harming both agricultural and animal husbandry practices.

The Horn of Africa – which includes Ethiopia, Somalia, and parts of Kenya – is drying faster than at any time in the last two millennia.[15] These environmental changes have spurred mass internal displacement and outward migration, as well as widespread malnutrition.[16] The Horn of Africa suffered a severe rainfall shortage, and in 2015 and 2016, droughts drove large-scale livestock deaths in rural areas in this region.[17] Hundreds of thousands of people were displaced as a result of food and water scarcity, and as many children suffered severe acute malnutrition.[18] In the setting of severe drought, heavy or even average seasonal rainfalls can be devastating. In April 2018, heavy rainfall occurring after 2 years of severe drought triggered massive flooding throughout Ethiopia, Somalia, and Kenya.[16] More than 700,000 persons were displaced as a result, many for a second time, after having previously been forced to leave uninhabitable dry land.[16] The same year, Southern Africa suffered a severe drought that triggered a water shortage crisis in Cape Town, South Africa.[19] These disaster cycles may forecast what is to come in regions most affected by or at risk for desertification.

In addition to desertification, climate change may render key agricultural regions more prone to flooding, salinization, and migrating crop pests whose life cycles are influenced by both temperature and humidity. These effects are expected to generate hefty demands on a strained food supply system and lead to higher food prices. Inflation-adjusted prices of the three most important staple grains – wheat, rice, and maize – may increase up to 106% by the year 2050.[20] Higher prices have been linked to reduced food intake among both urban and rural low-income populations, which may put already-vulnerable populations at even greater risk of malnutrition.[20]

Malnutrition has lasting consequences that hinder both physical and intellectual development. Evidence supports a link between climate, malnutrition, and poor growth – in both northern Kenya and Ethiopia, separate studies have linked perturbations in climate variables to childhood malnourishment and growth stunting.[21,22] Malnutrition also has numerous dermatologic implications. These include pellagra (niacin deficiency, Fig. 1), acrodermatitis enteropathica (zinc deficiency, Fig. 2), scurvy (vitamin C deficiency), phrynoderma (vitamin A deficiency), angular cheilitis (seen in riboflavin and other vitamin B deficiencies), alopecia (seen in biotin and other vitamin deficiencies), xerosis and dermatitis (a feature of numerous vitamin B deficiencies), poor wound healing, and heightened vulnerability to infection.

Figure 1 Pellagra (niacin deficiency). 21-year-old woman who presented with 3 months of poor stamina, lightheadedness, vertigo, poor appetite, and hyperpigmented, scaly plaques on photo-exposed areas including the face, neck, dorsal forearms, and dorsal hands. Her staple diet includes maize, with no regular access to meat or vegetables

The effects of climate change on the food supply have the potential to reverse decades of improvement in global living standards. Many African nations have only recently begun to recover from the long-lasting consequences of colonialism and armed conflicts. For example, after several years of rapid economic development, Ethiopia is on course to become a middle-income country. However, several factors now threaten its prosperity, including urban development at a pace that outstrips infrastructural capabilities, massive numbers of incoming refugees (Ethiopia is the second largest refugee-hosting country in Africa), and the consequences of climate change on both the food supply and communities living in desertified areas.[23,24]

Mass human displacement

Climate change triggers mass displacement, namely because when the natural resources of the land no longer support its inhabitants, they often choose to move. The most recent U.N. data show that an unprecedented 68.5 million people were displaced by either natural disasters or conflict at the end of 2017.[25] The same year, the Internal Displacement Monitoring Centre estimated 18.8 million *new* internal displacements worldwide as a result of natural disasters alone.[26] Within Africa, Somalia and Ethiopia saw the highest numbers – 899,000 and 434,000, respectively – of displaced persons.[26] In a study of skin diseases among refugees living in Chad, eczema flares and skin infections (especially tinea and scabies) were the most common diagnoses.[27]

Armed conflict

Numerous studies have demonstrated empiric relationships between higher ambient temperatures and political violence.[28] Natural disasters and armed conflict are also linked; one study identified a coincidence rate of 9% between armed-conflict outbreak and natural disasters.[29] Moreover, between 1980 and 2010, approximately 23% of conflict outbreaks in countries with high degrees of ethnic fractionalization coincided robustly with climate calamities.[29] Climate-related disasters promote armed conflict by triggering economic crises and/or mass displacement, both of which exacerbate preexisting ethnic and/or political tensions. In 2017, 5.5 million people in SSA were displaced as a result of armed conflict; this amounted to 46.4% of the global total that year, though the region is home to only 14% of the global population.[26] The countries with the most armed conflict-related displacement were the Democratic Republic of the Congo (2.2 million), Somalia (1.3 million), Ethiopia (1.2 million), South Sudan (932,000), and the Central African Republic (542,000).[26]

Transient housing status precipitated by displacement harms family and community financial security; the World Bank estimates that, by 2030, 100 million people could become impoverished as a direct result of climate change.[30] Mass displacement also contributes to the spread of communicable diseases via urban crowding, impaired clean water access, poor hygiene, disrupted healthcare services, and hampered vaccination efforts. By 2030, an estimated 70% of deaths among children younger than 5 years will occur in conflict-affected nations.[25]

Several dermatologic conditions are associated with mass displacement, housing instability, and political conflict, including ectoparasite infestation[31] and cutaneous leishmaniasis (CL).[32]

Climate change and infectious diseases

Several infectious microbes and their vectors are known to be directly sensitive to both temperature and humidity, and as such, the geographic range of these pathogens is heavily influenced by regional climate variation, in addition to the socioeconomic factors that determine the quality of public health infrastructure. Furthermore, extreme weather events trigger migrant and refugee crises that disrupt infectious disease reservoirs and contribute to overcrowding, which increases the risk for spreading communicable diseases.[25]

Vector-borne diseases

Vector-borne diseases account for approximately 17% of all infectious diseases and continue to be a significant public health

Figure 2 Acrodermatitis enteropathica (zinc deficiency). 4-month-old male who presented with irritability, diarrhea, and erosions around the mouth and perianal skin, present since 3 weeks of life

problem, particularly in Africa, where the climate is highly favorable for the transmission of these pathogens.[33] Long-term trends in warming are predicted to have the greatest negative impact in the highland regions of Eastern and Southern Africa, where moderate temperatures have thus far been relatively unfavorable for tropical pathogens and their vectors.[34]

Dengue fever, chikungunya, and Zika viruses

The *Aedes* mosquito genus transmits several viral pathogens including dengue fever, chikungunya, Zika, and yellow fever. Survival of this vector is optimized at 26–29 °C.[35] Over the last few decades, the worldwide vectorial capacity of the *Aedes aegypti* and *Aedes albopictus* species has risen continuously and peaked in 2016, the latest year for which data are available.[36] The increasing environmental suitability for this vector has contributed to dengue fever becoming one of the most rapidly spreading vector-borne diseases worldwide.[35] Cutaneous manifestations of dengue fever include a diffuse morbilliform rash; subsequent infection with a separate viral serotype may lead to dengue hemorrhagic fever, which may be fatal.[37]

Fewer epidemiological data are available for chikungunya and Zika viruses, both of which have become large-scale public health problems more recently. Chikungunya virus is thought to have originated in SSA.[38] Cutaneous manifestations include a diffuse morbilliform rash and chronic reticulate hyperpigmentation.[39] Patients may develop a chronic debilitating arthritis following acute infection.[39]

Zika virus was first isolated in Uganda in 1947, and the first human case was reported there in the 1960s.[40] When present, mucocutaneous manifestations include conjunctivitis and a morbilliform rash.[40] Because infected patients are frequently asymptomatic, it is challenging to assess the true prevalence of Zika virus in low-income African countries where serologies are not routinely used in diagnosis.[40]

Modeling studies predict climate-driven emergence and expansion of all *Aedes*-transmitted arboviruses at higher latitudes and higher elevations than previously experienced.[35] In Africa, this is expected to have the biggest impact in the highlands of East Africa.[35] Treatment for all three infections is supportive, as no specific therapies exist.

Leishmaniasis

Leishmaniasis is caused by protozoal parasites transmitted by phlebotomine sandflies.[41] The disease predominantly affects low-income persons and is linked to malnutrition, population displacement, and marginal housing status, as well as environmental disruptions such as deforestation, building of dams, and urbanization.[42] In Africa, all three clinical forms of leishmaniasis (visceral, cutaneous, and mucocutaneous) are endemic.[41] CL most commonly presents with nonhealing ulcers of exposed sites, often the head and neck (Fig. 3). Rates of visceral leishmaniasis are highest in East Africa, whereas CL occurs throughout North Africa as well as in the highlands of Ethiopia.[41] Recently, outbreaks have been reported in regions of Ethiopia where visceral leishmaniasis was not previously known to be endemic.[43] CL is also spreading to new areas where it was not reported previously.[44] The suspected reasons are spread of the reservoir or vector into new areas, possibly associated with the ecological changes such as deforestation.[45]

Figure 3 Cutaneous leishmaniasis. Patients from Ethiopia with nonhealing plaques of the face; image on right shows extensive scarring that may develop

Malaria

While malaria, caused by *Plasmodium* species that are transmitted by the *Anopheles* mosquito vector, has few and rare cutaneous manifestations (including urticaria, petechiae, and purpura),[46] it merits mention given its high prevalence throughout Africa and high associated morbidity and mortality. Malaria transmission is highest in warm, low-elevation zones with the regular rainfall that produces the surface water that facilitates *Anopheles* mosquito breeding. As such, it has historically been endemic in tropical African countries.[47] Malaria is known to be sensitive to climate variables, including temperature, humidity, and rainfall. Reproduction of *P. vivax* in mosquitoes takes 55 days at temperatures of 16 °C, 29 days at 18 °C, and only 7 days at 28 °C.[48] In Baringo County, Kenya, between 2000 and 2014, higher rainfall at a lag of 2 months resulted in increased malaria transmission across all four climate zones.[49] The same 2 months lag time was found in another study in South Africa.[50] Coinciding with global warming, there has been a steady increase in high-elevation areas within Africa that are suitable for malaria transmission.[51] In Ethiopia, Kenya, and Tanzania alone, approximately 75 million people live in newly vulnerable altitudes between 1,000 and 2,500 m.[47] Extreme weather events, particularly flooding, also affect transmission. In Uganda, extreme flooding was associated with a 50% increased risk of having a positive malaria diagnostic test during the post-flood period in villages bordering a flood-affected river versus those located farther from the flooding.[52]

Over the last several decades, substantial resources have been devoted to preventing malaria transmission and treating the disease once it is diagnosed. Climate change threatens to hinder the progress that has been made in this arena. In the future, climate information may be used to produce "malaria risk maps" that take into account heat, humidity, precipitation, and altitude, so that clinicians and public health workers can adapt to these changes.[47,53]

Communicable diseases

Dermatophytosis

Fungal growth and dispersal are known to be sensitive to changes in temperature and moisture; in fact, this partially accounts for the distribution of dermatophytes on the human body, as in tinea pedis, in which dermatophytes favor warm, moist body sites. Tinea corporis (Fig. 4) and tinea pedis have both been reported in higher frequencies in the aftermath of flooding.[54]

Tuberculosis

Tuberculosis transmission is classically associated with overcrowding and poor public health infrastructure. As such, displaced climate migrants, particularly those living in close quarters, such as refugee camps, are particularly vulnerable. Climate may also influence tuberculosis transmission more directly. In 2006, investigators in Cameroon recorded more tuberculosis cases in the wet season compared with the dry season.[55] Tuberculosis may have numerous cutaneous manifestations resulting from either direct inoculation of the organism or dissemination from a visceral site of infection (Fig. 5).

Human immunodeficiency virus (HIV)

Increased rates of HIV transmission are known to occur in persons living in concentrated, low-income settings, particularly in urban areas.[56] As such, climate migrants may be particularly affected. Moreover, many of the opportunistic infections that ultimately cause mortality in persons living with HIV infection are known to be sensitive to climate variables.[56] In a qualitative study in Zimbabwe, households in which a person is HIV infected consume nearly 50% more water compared to other households.[57] In this way, climate change-induced droughts may disproportionately affect households with HIV-infected patients. HIV has a myriad of cutaneous manifestations, many related to the opportunistic organisms that infect persons with HIV, particularly at advanced, untreated stages of disease.

Ebolavirus

Ebolavirus is a highly contagious organism that has become an increasing threat to the public health in recent years, with the most severe recent outbreak occurring in 2014. This form of hemorrhagic fever may present with unexplained bleeding or bruising, in addition to more classic viral symptoms (fever, malaise, headache, and gastrointestinal distress).[37] The is

Figure 4 Diffuse tinea corporis as a presenting sign of HIV infection. 30-year-old woman who presented with mild pruritus and a diffuse scaly skin rash lasting 7 months. Serology test was positive for HIV; KOH preparation was positive for dermatophytes

transmitted in humid tropical rainforests, where the temperature is moderate year-round. The seasonality of outbreaks suggests a potential role of climate. One study found that outbreaks between 1976 and 2014 were associated with higher absolute humidity and lower temperature.[58] Moreover, as with other vector-borne diseases, deforestation and other methods of environmental disruption can disturb animal reservoirs, contributing to periodic outbreaks.

Neglected tropical diseases

Neglected tropical diseases (NTDs) are a group of conditions that affect approximately 1 billion people, predominantly of low socioeconomic status, worldwide.[59] A significant proportion of this disease burden is experienced in Africa. The majority of NTDs have cutaneous manifestations. NTDs epitomize the interconnectedness of poverty and skin disease, serving both as an indicator of poverty and a factor responsible for perpetuating it. As a result of their high morbidity, NTDs have a significant negative impact on the economies of low-income countries, despite low overall prevalence levels.[60] Climate-sensitive NTDs with cutaneous manifestations are summarized in Table 2.

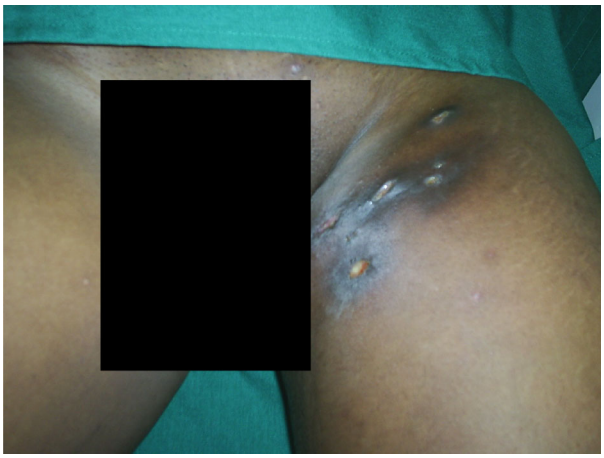

Figure 5 Scrofuloderma (cutaneous tuberculosis). 28-year-old woman who presented with purulent drainage and swellings on the left upper thigh for 2 years. GeneXpert test reported positive (medium), and the diagnosis was also confirmed the presence of AFB from the fine-needle aspirates. Tuberculosis is associated with poverty, overcrowding, and HIV infection

Vector-borne NTDs include lymphatic filariasis, onchocerciasis, leishmaniasis, human African trypanosomiasis, dengue fever, and chikungunya. Some of these were reviewed in the previous section. Lymphatic filariasis is a vector-borne infection endemic to the tropics.[61] Infected mosquitoes release parasitic worms into the bloodstream when taking a blood meal, and over time these may cause chronic, debilitating lymphedema.[61] Investigators have used ecological niche modeling to predict that a larger area of Africa – specifically the Sahel region (the transition zone between the Sahara Desert and the savannas of SSA), Zambia, Zimbabwe, and Angola – would become newly endemic for lymphatic filariasis as a result of climate change.[61]

Onchocerciasis, or "river blindness", is caused by the nematode parasite *Onchocerca volvulus* and transmitted by blackflies (*Simulium* species). The condition presents with debilitating pruritus and subcutaneous nodules.[62] Death of larvae in the eye can cause corneal clouding and eventually progress to permanent blindness.[62] Both the organism and its vector are known to be temperature-sensitive.[62]

Schistosomiasis is a water-borne disease prevalent throughout SSA and associated with high morbidity. Cutaneous manifestations may include pruritus or dermatitis associated with cutaneous penetration of the organisms.[63] Urticaria may occur 4–6 weeks later and, rarely, papulonodular lesions may develop

Table 2 Relationship between climate variables and neglected tropical diseases with cutaneous manifestations

Neglected Tropical Disease	Affected regions within Africa	Climate sensitivity	Clinical manifestations
Vector-Transmitted Diseases			
Leishmaniasis (*Numerous pathogenic species*) Vector: Phlebotomine sand fly	Visceral: Ethiopia, Somalia, South Sudan and Sudan[41] Cutaneous: Algeria[41]	Peak infectious risk occurs at 30–32°C[93] Vector reproduction declines above 40°C[93] Rainfall increases vegetation density and breeding sites[43,93]	Visceral: Fever, splenomegaly, hepatomegaly, skin necrosis. Post kala-azar dermal leishmaniasis Cutaneous: Non-healing skin ulcers that may heal with scars
Lymphatic filariasis (*Wuchereria bancrofti*) Vector: Most often *Anopheles* mosquito spp., which breeds in standing water	Equatorial Africa	Rainfall > 150 mm/year[61] Peak transmission: 25–35°C[61] Low altitude[94]	Unilateral or bilateral chronic lymphedema and elephantiasis. Chronic lymphedema may cause permanent disability[61]
Trypanosomiasis *(Trypanosoma brucei gambiense* and *rhodesiense*) Vector: *Glossina* tsetse fly	*T. brucei gambiense* (West & Central Africa) *T. brucei rhodesiense* (East Africa)	Ideal temperature range for transmission is 20.7–26.1°C[95] Temperature changes linked to shifting geographic range[96]	Fly bite may produce a nodule with an overlying eschar.
Dengue Fever and Chikungunya viruses Vector: *Aedes* mosquito species	Throughout tropical sub-Saharan Africa	Vector survival peaks at 26–29°C[35]	Morbilliform rash seen in both. Reticulate hyperpigmentation after chikungunya infection[39]
Onchocerciasis (*Onchocerca volvulus*), aka **River Blindness** Vector: *Simulium* (black) fly (breeds near fast-flowing rivers)	Throughout sub-Saharan Africa; different black fly species found in different climate zones[97]	Reproduction of forest flies peaks at 29°C; savannah flies at 30°C[97] Ideal water temp. range 22–33°C[97]	Severe, debilitating pruritus, subcutaneous nodules; death of larvae in eye leads to permanent corneal clouding that may progress to blindness.
Malaria (*Plasmodium* spp.) Vector: *Anopheles* mosquito spp.	Throughout sub-Saharan Africa in warm, low-elevation zones[47]	Mosquito reproduction fastest at 28°C.[48] Heavy rainfall and flooding linked to increased transmission[49,52]	Rare cutaneous manifestations may include urticaria, petechiae, purpura
Soil and/or water-borne diseases			
Tungiasis (*Tunga penetrans* sand flea) Organism burrows into skin, typically affecting the feet	Throughout sub-Saharan Africa	Case rates peak in dry season (Brazil)[83]	Red-brown macule nodule w/ central dark punctum. Flea engorgement swelling, erythema, pruritus, and/or pain[81]
Mycetoma (*Numerous causative bacterial and fungal species*) Pathogens enter into damaged skin, typically on the feet or hands	Chad, Ethiopia, Senegal, Somalia, Sudan[68]	Arid, hot climates with mild temperatures and intermittent heavy rainfall[69] Actinomycetoma more common in dry areas; eumycetoma seen in areas with higher rainfall.[69]	Painless subcutaneous nodules, sinuses; discharge containing grains. May cause fatal bone infection[68]
Chromoblastomycosis (Numerous spp., including *Fonsecaea pedrosoi*, *Cladophialophora carrionii, Phialophora verrucose*)[70]	Rural areas of Madagascar > other tropical areas throughout Africa[70]	Seen in warm, humid, tropical climates. High-risk occupations: farmers, coconut harvesters, lumberjacks[70]	Verrucous, crusted, and/or ulcerated nodules that resemble tumors or cauliflowers. Typically affects hands and/or feet[70]
Schistosomiasis (*Schistosoma haematobium and mansoni*) Intermediate host: freshwater snail	Lake regions of East Africa	Parasite and intermediate host are temperature sensitive. Transmission peaks at 22–27°C[64]	Transient pruritus or dermatitis at time of penetration. Urticaria 4–6 weeks later. Papulonodular lesions (delayed granulomatous hypersensitivity reaction) may develop[63]
Buruli ulcer (*Mycobacterium ulcerans*) Vector: *unknown*	Gulf of Guinea, Central, and Western Africa	Cases peak in rainy season[71] Linked to dam-induced flooding[72] Incidence highest in areas with abundant wetlands[73]	Large, non-healing skin ulcers Associated joint contractures may cause permanent disability.
Podoconiosis Acquired via barefoot contact with irritant volcanic soils	Central highlands of Ethiopia[86]	1,000–2,000 m elevation[86] Annual rainfall > 1,000 mm[86]	Skin nodularity, chronic leg edema[86] Prevent with closed-toe footwear
Communicable diseases			

Table 2 Continued

Neglected Tropical Disease	Affected regions within Africa	Climate sensitivity	Clinical manifestations
Ectoparasites: Scabies and Body Lice *Spread via skin-to-skin contact*	Widespread in Africa; linked to poor hygiene, low income, and high population density[77]	Increased incidence in climate migrants; linked to extreme weather events (drought, flooding, severe storms)	Scabies: erythematous papules/ nodules, burrows, dermatitis, prurigo nodules Body lice: eczematous dermatitis, prurigo nodules

as a delayed granulomatous hypersensitivity reaction.[63] The snail that serves as the immediate host of schistosomiasis has a temperature-sensitive life cycle.[64] More specifically, higher temperatures promote increased snail egg output.[64] Temperatures above 30 °C may negatively affect gametogenesis, suggesting a nonlinear range of thermal tolerability.[64] Schistosomiasis infections are predicted to increase by approximately 20% in the Lake Victoria region of East Africa as a result of rising water temperatures.[65,66] Conversely, some areas of Africa, including northern and eastern Kenya, South Sudan, and DR Congo, may become too hot and dry to sustain snail species; estimates show a 50% decrease in incidence in these regions.[65,67]

Mycetoma, either caused by fungi (eumycetoma) or bacteria (actinomycetoma), is associated with painless subcutaneous nodules. Actinomycetoma has been reported in dry areas of Africa, whereas eumycetoma often is seen in areas with higher rainfall.[68,69]

Chromoblastomycosis, a chronic fungal infection, is more prevalent in warm, humid, and tropical areas throughout Africa and rural areas of Madagascar. Cutaneous manifestations can include verrucous, crusted, and/or ulcerated nodules that resemble tumors or cauliflowers mostly on the hands and/or feet.[70]

Buruli ulcer (BU), a chronic, necrotizing disease of skin and soft tissue, is caused by *Mycobacterium ulcerans*. The incidence varies by season; in Akonolinga, Cameroon, the highest incidence of BU from 2002 to 2012 was reported in the rainy season; other investigators have also found the highest incidence to be in areas with abundant wetlands.[71–73]

Leprosy is an infectious NTD, the transmission factors of which are related primarily to unfavorable living conditions and social inequality. Leprosy primarily affects peripheral nerves, resulting in paralysis of affected muscles and loss of affected fingers and toes; other types of permanent deformities include nose disfigurement, loss of eyebrows, corneal ulcers, and blindness; stigma is also prevalent among affected patients. Although leprosy rates have declined across Africa in recent years, in some countries, the rates of newly registered cases have remained stagnant for the last 15 years.[74] Although no studies of climate sensitivity have been conducted in Africa, a recent study in Brazil found a seasonal case pattern for leprosy, with peaks in the fall and winter.[75] Additionally, numerous medications used to treat leprosy – including dapsone, clofazimine, and rifampicin – are known to be sensitive to temperatures greater than 30 °C. As such, affected patients may be particularly vulnerable during heat waves.[76]

Ectoparasite infestations classified as NTDs include scabies, pediculosis, and tungiasis. Scabies and pediculosis are directly transmitted from human to human, typically in situations of poor hygiene and overcrowding. For this reason, infestation occurs frequently in refugee camp settings.[77] Moreover, severe drought may lead to shortages of water for both drinking and personal hygiene, precipitating scabies outbreaks, as seen in Ethiopia in 2015.[78] Cutaneous manifestations of both scabies and body lice infestation may include diffuse pruritus as well as excoriations, eczematous dermatitis, and/or prurigo nodules caused by scratching and/or rubbing. Scabies infestation predisposes to secondary bacterial infection and even post-streptococcal glomerulonephritis.[79] Body lice may transmit several potentially life-threatening infections including *Bartonella quintana* (the cause of trench fever), *Borrelia recurrentis* (the cause of louse-borne relapsing fever), and *Rickettsia prowazekii* (the cause of Epidemic Typhus).[80]

Tungiasis is an ectoparasite infestation caused by *Tunga penetrans*, a flea that burrows into the skin on the feet, where it carries out its 6-week life cycle.[81] Early lesions appear as red-brown macules; these evolve into nodules with a central dark punctum. Subsequent flea engorgement secondary to egg production may cause swelling, erythema, pruritus, and/or pain.[81] The condition may affect any person, including a non-native traveler, who walks barefoot in endemic regions. However, the disease burden is greatest in persons living in endemic areas that cannot afford regular use of closed-toe shoes.[82] In Brazil, tungiasis incidence has been shown to peak in the dry season;[83] seasonality in Africa has not been established.

Podoconiosis (endemic nonfilarial elephantiasis) is a noninfectious NTD caused by prolonged bare feet exposure to soil. It presents with verrucous plaques and nodules on the lower extremities (Fig. 6). The condition most commonly affects people living in the highlands of tropical Africa, especially Ethiopia.[84] As with other NTDs, it carries a significant physical, social, psychological, and economic impact. The main reasons for prevailing discrimination against patients and affected families are the erroneous belief that the disease cannot be prevented, treated, or controlled; association of the disease with

curses; and the belief that the disease runs in families through invisible hereditary factors.[85] The condition can be prevented by wearing closed-toe shoes. It predominates in places located at 1,000–2,000 m of elevation that experience annual rainfall greater than 1,000 mm.[86]

Development versus environmental conservation and the path forward

Climate change will make it challenging to achieve many of the U.N.'s Sustainable Development Goals set forth and adopted by all member states in 2015. These ambitious items included zero hunger, no poverty, quality education, clean water/sanitation, affordable energy, decent work, infrastructure, sustainable communities, responsible consumption, climate action, life on land and below water, and peace/justice/strong institutions.[87]

Rapid economic development requires substantial increases in energy demand, and many low- and middle-income nations have been asked by recent multinational agreements to continue their development efforts under constraints that were not in place during the industrial revolutions of modern high-income nations. This raises issues of distributive justice that have been the subject of debate among and within international organizations.

Figure 6 Podoconiosis. 30-year-old woman who presented with bilateral leg swelling that began with unilateral left foot swelling 12 years previously. She had been bare-footed all her life and lived in a podoconiosis-endemic area

Climate compatible development (CCD) refers to "development that minimizes the harm caused by climate impacts, while maximizing the many human development opportunities presented by a low-emissions, more resilient future."[88] Examples of CCD in low- and middle-income African countries may include improved cook stoves, installation of solar lights, and improved forestry and farming techniques.[88] Investigators studying the adoption of CCD in three regions in Malawi identified that these programs could be successful, though not all were.[88] On average, two to three benefits each were experienced by households, and wealthier, youth-headed, and male-headed households benefited more than others.[88]

Increased investment in climate compatible African development could occur through various means including (i) improving public health and road infrastructure, (ii) providing incentives to import or build newer cars with lower baseline carbon emissions, (iii) supporting comprehensive drug therapy to treat NTDs, (iv) building institutions that train health professionals, (v) investing in agricultural production systems that are less vulnerable to the whims of extreme weather events, (vi) developing early warning systems for extreme weather events, and maintaining and improving current environmental health regulations, and (vii) improving water and air quality standards.[89] Several African nations have pledged to dedicate their resources to these ends and more. All African U.N. member nations signed onto the Paris Climate Accords in December 2015, and as of April 2019, all but Libya, South Sudan, Angola, and Eritrea have ratified the agreement at the level of their individual governments.[90] This landmark multinational agreement included pledges to provide monetary assistance of 100 billion USD annually to low- and middle-income countries so that they may more effectively combat climate change.[90] Unfortunately, as of 2018, annual financing for mitigation was falling well short of this pledge.[6]

Ethiopia has specifically pledged to work toward establishing a climate-resilient green economy by the year 2025.[91] In their stated plan, the Ethiopian government has emphasized four key areas of focus, including crop and livestock production, forestry, expansion of renewable energy use and exportation, and investments in technology to increase energy efficiency.[92] Importantly, making these changes will require heavy upfront investment of more than 150 billion USD.[92]

Preparing for and addressing the myriad health consequences of climate change in Africa require increased funding for research.[33,89] Less than 10% of papers related to health and climate change that were published in 2017 focused on Africa specifically.[6] Ramirez *et al*[83] recently called attention to several programs that are actively devoted to assessing and mitigating the population health vulnerabilities to vector-borne diseases in Africa. Better epidemiological data and an improved understanding of the relationship between specific climate variables associated with increased infection transmission may enable

the development of early warning systems that more effectively protect patients.[33] Moreover, enhanced understanding of the changing climate of a specific locale may help communities adapt to new infectious risks, as when malaria begins to affect patient living at higher altitudes as a result of sustained higher temperatures. African governments, international institutions such as the U.N., and international nongovernmental organizations alike should commit grant funding to support these and other projects.

Conclusions

Climate change is expected to exert more negative effects on Africa than on any other continent and threatens to undermine many of the public health gains that have been made over the last several decades via mass human displacement and exacerbation of environmentally sensitive diseases. Many African nations have made strides toward addressing the sociological and medical impacts of climate change. Dermatologists worldwide should be aware of the way in which climate change disproportionately threatens health in low- and middle-income countries and become well versed in the diseases that may be exacerbated or that may re-emerge as a result.

Questions (answers provided after references)

1 Which of the following parameters is associated with climate change?
- a Higher temperatures
- b Poor air quality
- c Extreme weather events
- d Malnutrition
- e All of the above

2 Each of the following patient populations is especially vulnerable to extremely high temperatures, as seen increasingly in recent heat waves, EXCEPT:
- a Elderly patients
- b Patients taking antihistamines
- c Neonates
- d Patients with lamellar ichthyosis
- e Patients with psoriasis

3 Which of the following diseases is not transmitted by mosquitoes
- a Malaria
- b Dengue fever
- c Zika virus
- d Chikungunya
- e Schistosomiasis

4 Deficiency of which of the following nutrients presents with a photosensitive dermatitis and diarrhea?
- a Vitamin A
- b Vitamin B3 (Niacin)
- c Zinc
- d Vitamin B12
- e Vitamin D

5 All of the following skin conditions have been directly linked to poverty and overcrowding EXCEPT:
- a Cutaneous tuberculosis
- b Scabies
- c Pediculosis
- d Chikungunya
- e Leishmaniasis

6 Which of the following diseases is correctly paired with its vector?
- a Dengue fever, *Anopheles* mosquito spp.
- b Onchocerciasis, freshwater snail
- c Lymphatic filariasis, *Anopheles* mosquito spp.
- d Chikungunya, *Aedes* mosquito genus.
- e Trypanosomiasis, Phlebotomine sand fly spp.

7 Which of the following conditions may be effectively prevented via the use of closed-toe footwear?
- a Onchocerciasis
- b Tungiasis
- c Lymphatic filariasis
- d Buruli ulcer
- e Schistosomiasis

8 In which of the following countries is podoconiosis often seen?
- a Ethiopia
- b Tunisia
- c Egypt
- d South Africa
- e All of the above

9 Which of the following diseases is associated with nonhealing skin ulcer(s)?
- a Schistosomiasis
- b Dengue fever
- c Chikungunya
- d Leishmaniasis
- e Tungiasis

10 Which of the following diseases is associated with a morbilliform rash?
- a Malaria
- b Dengue fever
- c Lymphatic filariasis
- d Mycetoma
- e Onchocerciasis

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Answers to Questions

1 (e)
2 (e)
3 (e)
4 (b)
5 (d)
6 (c)
7 (b)
8 (a)
9 (d)
10 (b)