Int J Med Rev 2021 March;8(1): 25-31

doi 10.30491/ijmr.2020.241608.1128

INTERNATIONAL JOURNAL OF MEDICAL REVIEWS

Mini Review

Implications of Health Research and Climate Change Mitigation on the Transmission of Influenza Viruses in Africa

Oritsetimeyin Victoria Arueyingho [1] *

[1] Faculty of Pharmacy, Girne American University, Karaoglanoglu, Kyrenia, Turkey

* **Corresponding Author:** Oritsetimeyin Victoria Arueyingho, Faculty of Pharmacy, Girne American University, Karaoglanoglu, Kyrenia, Turkey. E-mail: timeyinarueyingho@gau.edu.tr

Received July 28, 2020; **Accepted** August 23, 2020; **Online Published** March 5, 2021

Abstract

As the climate of the earth changes rapidly, its devastating effects on human health becomes more evident. Possible effects of climate change on human health include higher rates of respiratory diseases, increased prevalence of vector-borne, zoonotic and waterborne diseases, food and water scarcity, as well as malnutrition. Worsened conditions are predicted in Africa primarily due to the inadequacy of optimum public health systems and climate mitigative controls. Addressing the implications of climate change mitigation and public health research could have substantial benefits to human health, particularly in the transmission of infectious diseases such as influenza. This review aims to explore available literature on the current effects of climate change in Africa and how it influences the incidence and prevalence of influenza, thereafter making recommendations to ameliorate current conditions by encouraging interdisciplinary collaborations.

Introduction

Influenza viruses are members of the family of *Orthomyxoviridae* which are primarily made of segmented genomes and single-stranded negative RNA. This family is composed of four genera types including A, B, C and Thogotovirus. Influenza A and B viruses are infectious to human beings and are responsible for a variety of acute respiratory diseases; these are therefore the major clinically relevant genera to humans. In addition, the Influenza A virus is further classified into subtypes based on antigenic and genetic differences in the membrane glycoproteins hemagglutinin and neuraminidase; two of these subtypes are currently in circulation among humans.[1] A systematic review of research published from 1980 to 2009 on seasonal influenza epidemiology in sub-Saharan Africa conducted by Bradford.,[2] revealed that Influenza was highly seasonal in southern Africa. The review also highlighted the absence of relevant data from Sub-Saharan Africa alongside information explaining the possible relationship between climatic changes in these regions and the incidences of influenza.

Climate change as defined by National Geographic is a long-term shift in global or regional climate patterns. The impact of climate change is not negligible as it can be observed in different sectors ranging from agriculture, water resources, biodiversity and more importantly, health. The prospective influence of climate change on the health of humans are consequential, ranging from direct effects such as flooding and heat stress, to indirect impacts including changes in the transmission of diseases.[3] Accelerated adjustments in global climatic conditions are already affecting human health in different ways, one of which is by altering the epidemiology of climate-sensitive pathogens.[4] A positive relationship has therefore been established between changes in climatic conditions and the epidemiology of diseases. Evidence based reports have revealed that health outcomes are highly sensitive to variations in the climate. Therefore, it is unavoidable that long-term climate changes would have an effect on global population health.[5] The 2004 Nobel Prize winner, Dr. Wangari Maathai predicted that Africa would be hit hardest by changes in Climate. Other predictions include the incidence of intense tropical cyclones, higher sea levels and general increases in temperature. Therefore there is very high confidence on the contraction and expansion of vector borne diseases, increase in malnutrition and cardio-respiratory diseases from changes in air quality and an

increase in the range of infectious diseases.[6] Currently, in Southern Africa, while extreme weather events are becoming more noticeable, vector borne diseases are becoming more prominent.[7]

The World Health Organization (WHO) recommends routine epidemiological and virological scrutiny in order to prevent the outbreaks of communicable diseases. It is unfortunate that epidemiological information on influenza outbreaks including its negative impacts in African countries and its relationship to climate change are insufficient. This review therefore aims to investigate the spread of influenza viruses in Africa and its relationship to climate change, while highlighting the importance of health research in the mitigation of the negative impacts of climate change.

Incidence and Prevalence of Influenza Viruses in Africa

Respiratory diseases are one of the major causes of mortality throughout the globe. Infections from the influenza virus alone may cause estimated 290,000–650,000 deaths per year according to the WHO.[8] In equatorial regions, influenza could occur throughout the year. However, in the Northern Hemisphere, the season of influenza typically starts in the beginning of autumn, peaks in the middle of February, and concludes towards the end of spring of the following year. This tells us that the weather and climate influence the incidence and prevalence of influenza globally.[9] Conclusive data on the seasonal flu was reported by the Centers for Disease Control and Prevention (CDC) even as the coronavirus disease continued to spread. In the United States alone, the CDC reported 39 – 56 million illnesses and 24 – 62 thousand deaths between the 1st of October 2019 and the 4th of April 2020.[10]

In spite of epidemiological research conducted on seasonal influenza, overall infection patterns have not been described in details based on broad geographical scales and for specific types of the influenza virus.[11] Research materials and reports that describe the circulation of influenza globally have highlighted that there is very little data from Africa; while quite recently, the burden of influenza in Africa was thought to be insignificant.[12] There however have been sporadic reports from several African countries such as South Africa, the Gambia, Congo, Senegal, Kenya, Madagascar, Ethiopia and Ivory Coast that has indicated that there might be regular incidences of the influenza virus causing epidemics. In a typical setting in Africa, influenza is not distinguishable from other infectious diseases that may cause fever. Malaria is the most common culprit of misdiagnosis because it is an important infectious disease and is thought to be the main cause of considerable annual morbidity and mortality.[13] However, diagnosing influenza like diseases could be challenging and it affects reports on the incidence and prevalence of influenza viruses specifically in these regions. Research conducted by Maria Yazdanbakhsh and Peter G. Kremsner concluded that influenza is prevalent in Africa and may have significant impacts on morbidity and mortality, hence, proper investigative systems should be set up to aid in understanding the epidemiology of influenza in Africa.[12]

Sporadic data suggest that there is an increased risk of influenza-associated mortality in low-income settings in regions such as sub-Saharan Africa.[14] The high prevalence of comorbid conditions such as malaria, HIV/AIDS and tuberculosis have been thought to contribute to the severity of influenza and subsequent mortality in Africa.[2] In South Africa, HIV/AIDS and other coinfections such as pneumonia and tuberculosis contributed to increased deaths among influenza virus positive patients. A research studying the prevalence of influenza-associated lower respiratory tract infections conducted in South Africa revealed that the incidence of these infections was 4-8 times greater for HIV-infected individuals compared to HIV-uninfected individuals. Findings from this research therefore indicated that HIV-infected individuals were at greater risk for severe illnesses related to influenza and thus should be prioritized for influenza vaccination.[15] Similar research revealed that influenza-associated mortality rates were 3.8 times higher in adults between the ages of 25 and 54, especially since this was the age group with the highest seroprevalence of HIV.[16]

A research that involved a case series from eight African countries was conducted to identify severe acute respiratory illnesses and the associated mortality rates. The countries that participated include the Democratic Republic of Congo, Kenya, Madagascar, Malawi, Rwanda, South Africa, Tanzania and Uganda. It was observed that Case-Fatality Proportion (CFP) was greater among countries with a systematic death

reporting approach than among those with sporadic reporting and a conclusion was drawn that few African countries systematically collect data on the outcomes of hospitalized patients with respiratory illness, thereby re-emphasizing the importance of health research and surveillance systems.[17] Similar research was conducted to establish the epidemiology of influenza in eight West African countries (Burkina Faso, Cote d'Ivoire, Mali, Mauritania, Niger, Nigeria, Sierra Leone and Togo) and loopholes in the surveillance system were identified, as there were insufficient data on adults and geriatrics.[18]

Climate Change in Africa

Africa, in spite of its low contribution to GHG emissions, remains the most susceptible continent. The continent faces exponential collateral damage, posing systemic risks to its public health, agriculture, water and food systems and infrastructural investments.[19] The Intergovernmental Panel on Climate Change (IPCC) prepares comprehensive assessment reports about knowledge on climate change, potential impacts and options for response. Their 2018 report highlighted severe consequences of a temperature increase above 1.5°C in Africa.[20] However they claim that it is still possible to limit rise in global temperature to 1.5° C—if, there are "rapid and far-reaching transitions in land, energy, buildings, transport, and cities".[21] Dramatic consequences have been observed in Sub-Saharan Africa with climate extremes becoming more frequent and intense over the past decades[22], it is also projected that temperature increases in this region (Sub-Saharan Africa) would be higher than global mean temperature changes.[23] Increases would even be more significant if the global mean temperature were to reach 2°C, with notable changes in the occurrence and intensity of temperature extremes in all sub-Saharan regions.[24] Large increases in the number of hot days both at 1.5°C and 2°C are projected to be displayed in West and Central Africa; this is primarily due to the relatively small inter-annual present-day variability in this region.[24] There are therefore benefits of limiting climate change to 1.5° C because every bit of additional warming adds greater risks for Africa in the form of greater droughts, more heat waves and the spread of infectious diseases.[21]

In West Africa, climate has evolved in response to elevated anthropogenic GHG forcing which is projected to increase.[25] Most countries in West Africa will therefore have to cope with shorter rainy seasons, generalized torrid, dry and semi-dry conditions, and more intense extreme precipitations.[26] Greatest warming is anticipated in the Sahel which is a semi-arid region lying south of the Sahara desert.[27,28] Vulnerability to climate change in West Africa is compounded by high dependence on rainfed agriculture, population growth, poor public health systems and inadequate access to safe water and other hygienic facilities. South Africa on the other hand has experienced a mean annual temperature increase by at least 1.5 times the observed global average of 0.65°C and extreme rainfall events over the past 50 years.[29] These changes in climate pose a notable threat to the public health and biodiversity of South Africa and Africa as a continent.[30]

Effect of Climate Change on the Spread of Influenza Viruses in Africa

It is an established fact that climate change has a direct impact on the spread of diseases and seasonal infectious outbreaks.[31] Africa, as one of the most vulnerable continents to climate change, would be severely hit by adverse changes in the climate. Although there might be some beneficial health effects such as reduction in the seasonal winter-time peak in deaths in temperate regions, there would be adverse effects in the spread of disease due to climate change. The IPCC projects that there would be three kinds of health impacts due to climate change, they include: those that are directly due to extreme weather, health consequences due to environmental changes and other health consequences that may occur due to displaced populations in the wake of climate induced economic dislocation.[31] In reference to the spread of disease, the impact of climate change on the spread of influenza viruses is not negligible. This fact was confirmed in a study led by Sherry Towers in Arizona State University which concluded that there would be early and severe influenza seasons occurring after warmer than average winters, in layman terms - more severe flu seasons would occur due to climate change.[32] Increasing temperatures can therefore lead to the increased transmission of diseases either through direct action on infectious agents or on vectors, or changes in host behavior.[33]

Several species of birds act as biological or mechanical

carriers of human pathogens as well as of vectors of infectious diseases, and many of these birds are migratory species- flying long distances through continents.[34] Climate change has been discovered to be responsible for changes in advancement in breeding and migration dates of several bird species, their population and their population dynamics all over the world.[35] The spread of H5N8 avian influenza (HPAI) in Africa can be attributed to the migration of several birds of the H5 Goose/Guangdong/96 lineage from Asia.[36,37] After the first recorded attack of HPAI in Eastern Africa, a series of H5N8-HPAI outbreaks were also recorded in the Democratic Republic of Congo and all these could be attributed to the influx of Palearctic waterfowls and overwintering ducks.[38] Therefore, it is generally accepted that migratory birds, most especially the waterfowl, play critical roles in the maintenance and spread of influenza A viruses. Climate change and environmental alterations have also been thought to also be responsible for the mutations undergone by influenza viruses and the jumps from one species to another.[33]

Human influenza A has been known to cause seasonal epidemics known as the flu season. Pandemics can even occur when a new and very different influenza A virus emerges. This should not be mistaken for pandemics such as COVID-19 that are caused by coronaviruses.[39] In addition to influenza, the Wildlife Conservative Society predicts that climate change may exacerbate the spread of other diseases such as cholera, Ebola and yellow fever, and these would have a negative impact on Africa due to poor infrastructure and vaccination facilities.[40] A large percentage of global pandemics have been due to viruses that affect the respiratory system and possibly give similar symptoms to that of influenza. Poverty has been implicated as one of the causes of the spread of these infectious diseases in Sub-Saharan Africa; in the next few decades, the effects of climate change will also be progressively and intensively felt across the African continent due to the interaction between climate change and urbanization.[41] It is predicted that there may be shifts in the geographic distribution of vector-borne and zoonotic diseases, thereby increasing the pressure in areas that were not susceptible to influenza outbreaks and other viral infections. Temporarily, health systems may be unprepared for prevention, diagnosis and treatment and over time, populations that were previously exposed would continue to be challenged by limited natural immunity and new disease interaction.[42] We can conclusively say that the effect of climate change on the spread of influenza in Africa (especially regions such as South-Africa in which influenza is highly seasonal[2] cannot be overlooked as it promises to be progressively intense if public health infrastructure, research and policies are repeatedly ignored.

The Impact of Health Research and Climate Change Mitigation on the Spread of Influenza Viruses in Africa

Climate change mitigation refers to efforts to inhibit the emission of Greenhouse Gases (GHG), thereby reducing atmospheric concentrations to levels that would prevent dangerous anthropogenic interference. The GHG such as Carbon Dioxide, Methane and Nitrous Oxides encourage heat trapping thereby making the Earth hotter than it's supposed to be; greenhouse gases are therefore one of the indicators of climate change.[43] According to the International Energy Association (IEA), the concentration of CO_2 in the atmosphere is limited to 450ppm in the proposed 'mitigation action' scenario compared to 1000ppm levels that the world is currently heading towards.[44] Global climate change mitigation is therefore essential for the reduction of GHG that would eventually protect less developed regions of the world, in this case, Africa. The Organization for Economic Co-operation and Development (OECD) has mimicked several possible scenarios for the ambitious reduction of GHG's and they discovered that major changes in behavior and methods of production will be needed to achieve GHG mitigation with the lowest possible costs.[45] Deforestation as highlighted by the OECD has been a major contributor to GHG's because it encourages the release of large volumes of CO_2 emissions into the atmosphere. Mitigation reference scenarios entail no further action, but aggressive policies to boost reforestation and quit deforestation may significantly contribute to the reduction of GHG's.[45] Several other measures for mitigating climate change include opting for renewable energy,[46] promoting sustainable mobility and public transportation,[47] promoting agriculture,[48] increasing taxes on fossil fuels and other CO_2 emission markets,[49] restoring damaged ecosystems[50] and most importantly

creating policies that would promote health research and mitigation of climate change.[51]

The insufficiency of data on seasonal-influenza epidemiology in Sub-Saharan Africa would negatively affect the ability of the government and other non-governmental organizations to identify the disease burden of influenza, strengths and weaknesses that may affect policy decisions, and other epidemiological traits of the region.[2] The data from Sub-Saharan Africa are inadequate to allow most countries to prioritize strategies for the prevention and control of influenza.[52] Enhancing knowledge about influenza transmission and other epidemiological factors is crucial to upgrade surveillance networks and to develop accurate models of prediction to enhance public health intervention strategies e.g. vaccination campaigns. While health research is not negligible, the positive relationship between climate change and the spread of infectious diseases such as influenza makes it obvious that attempts for effective change can majorly be attained through collaborative policies and strategies that would encourage mutual growth. A step in the right direction was taken on the 22nd of April 2016 at the United Nations Secretariat in New York, where about 175 world leaders signed what is called the *Paris Agreement*. On the same day, 47 African Member states signed the agreement and two ratified it. The Agreement is particularly critical for Africa, which is extremely susceptible to the impact of climate change. The Agreement is expected to help African countries with secure funding and viable technology to mitigate climate change, and develop renewable energy resources.[31,53] Simultaneous progress in public health research and climate mitigative procedures in African countries would therefore reduce the incidence and prevalence of infectious diseases such as influenza.[54]

The Engagement of the Health Sector in Climate Change Policies and Planning in Africa

The existence of climate change and its impact is already an established fact, but some giant questions remain; what measures of adaptation exist in the public health sector of African countries in response to climate change? What is the level of engagement of various health sectors to climate change policies in Africa? Are there existing policies and infrastructural planning systems which have primarily focused on mitigating climate change in Africa?

The Fifth Assessment Report of the IPCC-AR5 projected that sub-Saharan Africa may most likely have the greatest burden of mortality due to climate changes by the year 2030 [55] and that the impact of climate change would be grossly observed between the years 2030 and 2050.[56] Projections made by the World Health Organization show an increase in extreme weather and climate related deaths by the 2050's, with exposure to heat resulting in over 100,000 deaths per year.[55] Infectious food and vector-borne diseases, as well as communicable diseases may most likely be exacerbated by climate change.[57] With all these available information, how are health systems in Africa adapting to climate change policies and what is their level of engagement?

An existing research answered these questions by reviewing measures of adaptation from 21 African countries based on their National Communications to the United Nations Framework Convention on Climate Change.[58] The sampled countries include Botswana, Gambia, Egypt, Eritrea, Ghana, Guinea-Bissau, Rwanda, Lesotho, Malawi, Mauritius, Namibia, Uganda, Kenya, Sierra Leone, South Africa, Zambia, Swaziland, Seychelles, Nigeria, Sudan and Zimbabwe. It was discovered that 18 out of these 21 countries were either implementing or considering implementing measures of adaptation to climate change, while the remaining countries were silent (including 30 other African countries that were not assessed during the research). Results from the study revealed that Lesotho, Nigeria, Rwanda, South Africa and Egypt were already implementing early warning systems, while Uganda and Zambia were still considering this operation. Public education and awareness were already implemented in Gambia, Malawi, Nigeria and Rwanda, while the development of climate change related policies were already in-play in Lesotho, South Africa, Uganda and Egypt. This is while most of the studied countries were still considering creating policies that encourage inter-professional collaborative efforts for the purpose of climate change mitigation. The biggest observed challenge was that of public health infrastructure and technology. Unfortunately only The Gambia, South Africa and Egypt seem ready to handle climate change related public health challenges due to their system of governance that encourages optimum investment in health technological systems.[58] These results show that there

is still much more work to be done within the next decade as apparently, most African countries are not prepared for the devastating effects of climate change. Policy actions and other mitigative strategies will therefore be crucial in the coming decade to achieve globally agreed upon goals that would eventually decarbonize the economy and build resilience to a warmer, more extreme climate.[59] In most African counties however, strengthening the general health sector is observed as a form of climate change adaptation, hence making it more difficult to differentiate between implementing climate change adaptation policies and plans from general health sector planning.[60]

Conclusion

Although there is inadequate data on the epidemiology of influenza in Africa, it is an undoubted fact that thousands have died overtime due to this disease. Poor infrastructure, illiteracy and poverty have contributed to the transmission of infectious diseases, poor diagnosis, prevention and treatment. Research has proven that negative progressive changes in climate could result in adverse health effects such as severe seasonal influenza outbreaks. The implication of this in addition to the dilapidated available infrastructure in most African countries would be devastating. Interdisciplinary collaboration is therefore necessary for further research, policy creation and overall development. While public health scientists would be working hard to reduce the incidence and prevalence of infectious diseases such as influenza; climatologists, wild life conservativists, government officials, research scientists and members of other disciplines are intended to create collaborative efforts to help mitigate the negative effects of climate change.

References

1. Earn DJ, Dushoff J, Levin SA. Ecology and evolution of the flu. Trends in ecology & evolution. 2002;17(7):334-40. doi:10.1016/S0169-5347(02)02502-8
2. Gessner BD, Shindo N, Briand S. Seasonal influenza epidemiology in sub-Saharan Africa: a systematic review. The Lancet infectious diseases. 2011;11(3):223-35. doi:10.1016/S1473-3099(11)70008-1
3. Huntingford C, Hemming D, Gash JH, Gedney N, Nuttall PA. Impact of climate change on health: what is required of climate modellers?. Transactions of the Royal Society of Tropical Medicine and Hygiene. 2007;101(2):97-103. doi.org/10.1016/j.trstmh.2006.11.001
4. Mirsaeidi M, Motahari H, Taghizadeh Khamesi M, Sharifi A, Campos M, Schraufnagel DE. Climate change and respiratory infections. Annals of the American Thoracic Society. 2016;13(8):1223-30. doi:10.1513/AnnalsATS.201511-729PS
5. Campbell-Lendrum DH, Corvalan CF, Prьss Ustьn A. How much disease could climate change cause. Climate change and human health: risks and responses. Geneva: WHO. 2003:133-58.
6. Conway G. The science of climate change in Africa: impacts and adaptation. Grantham Institute for Climate Change Discussion Paper. 2009;1:24.
7. Chersich MF, Wright CY, Venter F, Rees H, Scorgie F, Erasmus B. Impacts of climate change on health and wellbeing in South Africa. International journal of environmental research and public health. 2018;15(9):1884. doi:10.3390/ijerph15091884
8. World Health Organization. https://www.who.int/influenza/surveillance_monitoring/bod/en/. 2020. Accessed July 23, 2020.
9. Nguyen HH. Medscape. https://emedicine.medscape.com/article/219557-overview#a6. 2020. Accessed July 23, 2020.
10. Rochester Regional Health. https://www.rochesterregional.org/news/2020/01/flu-season-2020. 2020. Accessed July 23, 2020.
11. Finkelman BS, Viboud C, Koelle K, Ferrari MJ, Bharti N, Grenfell BT. Global patterns in seasonal activity of influenza A/H3N2, A/H1N1, and B from 1997 to 2005: viral coexistence and latitudinal gradients. PloS one. 2007;2(12):e1296. doi:10.1371/journal.pone.0001296
12. Yazdanbakhsh M, Kremsner PG. Influenza in Africa. PLoS Med.2009;6(12):e1000182. doi:10.1371/journal.pmed.1000182
13. Mahdavi SA, Raeesi A, Faraji L, Youssefi MR, Rahimi MT. Malaria or flu? A case report of misdiagnosis. Asian Pacific journal of tropical biomedicine. 2014;4:S56-8. doi:10.12980/APJTB.4.2014C932
14. Lozano R, Naghavi M, Foreman K, Lim S, Shibuya K, Aboyans V, et al. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. The lancet. 2012;380(9859):2095-128. doi:10.1016/S0140-6736(12)61728-0
15. Cohen C, Moyes J, Tempia S, Groom M, Walaza S, Pretorius M, et al. Severe influenza-associated respiratory infection in high HIV prevalence setting, South Africa, 2009–2011. Emerging infectious diseases. 2013;19(11):1766. doi:10.3201/eid1911.130546
16. Cohen C, Simonsen L, Sample J, Kang JW, Miller M, Madhi SA, et al. Influenza-related mortality among adults aged 25–54 years with AIDS in South Africa and the United States of America. Clinical infectious diseases. 2012;55(7):996-1003. doi:10.1093/cid/cis549
17. McMorrow ML, Wemakoy EO, Tshilobo JK, Emukule GO, Mott JA, Njuguna H, Waiboci L, Heraud JM, Rajatonirina S, Razanajatovo NH, Chilombe M. Severe acute respiratory illness deaths in sub-Saharan Africa and the role of influenza: a case series from 8 countries. The Journal of infectious diseases. 2015;212(6):853-60. doi:10.1093/infdis/jiv100
18. Nzussouo NT, Duque J, Adedeji AA, Coulibaly D, Sow S, Tarnagda Z, et al. Epidemiology of influenza in West Africa after the 2009 influenza A (H1N1) pandemic, 2010–2012. BMC infectious diseases. 2017;17(1):1-8. doi:10.1186/s12879-017-2839-1
19. African Development Bank Group. https://www.afdb.org/en/cop25/climate-change-africa. 2020.
20. Allen MR, Dube OP, Solecki W, Aragyn-Durand F, Cramer W, Humphreys S, et al. Framing and context. Global warming of. 2018;1(5).
21. Shepard D. Global warming: Severe consequences for Africa: New report projects greater temperature increases. Africa Renewal. 2019;32(3):34. doi:10.18356/98ededc9-en
22. Paeth H, Fink AH, Pohle S, Keis F, Mдchel H, Samimi C. Meteorological characteristics and potential causes of the 2007 flood in sub-Saharan Africa. International Journal of Climatology. 2011;31(13):1908-26. doi:10.1002/joc.2199
23. Weber T, Haensler A, Rechid D, Pfeifer S, Eggert B, Jacob D. Analyzing regional climate change in Africa in a 1.5, 2, and 3 C global warming world. Earth's Future. 2018;6(4):643-55. doi:10.1002/2017EF000714
24. Hoegh-Guldberg O, Jacob D, Bindi M, Brown S, Camilloni I, Diedhiou A, et al. Impacts of 1.5 °C global warming on natural and human systems. Global warming of 1.5 °C An IPCC Special Report. 2018.

25. Liousse C, Assamoi E, Criqui P, Granier C, Rosset R. Explosive growth in African combustion emissions from 2005 to 2030. Environmental Research Letters. 2014;9(3):035003. doi:10.1088/1748-9326/9/3/035003
26. Sylla MB, Nikiema PM, Gibba P, Kebe I, Klutse NA. Climate change over West Africa: Recent trends and future projections. Adaptation to climate change and variability in rural West Africa. 2016:25-40. doi:10.1007/978-3-319-31499-0_3
27. Nicholson SE. The West African Sahel: A review of recent studies on the rainfall regime and its interannual variability. International Scholarly Research Notices. 2013;2013. doi:10.1155/2013/453521
28. Climate Risk Profile: West Africa. USAID; 2018. https://reliefweb.int/report/world/climate-risk-profile-west-africa
29. Ziervogel G, New M, Archer van Garderen E, Midgley G, Taylor A, Hamann R, et al. Climate change impacts and adaptation in South Africa. Wiley Interdisciplinary Reviews: Climate Change. 2014;5(5):605-20. doi:10.1002/wcc.295
30. Department of Environmental Affairs. South Africa's second national communication under the United Nations Framework Convention on Climate Change. 2010.
31. McMichael AJ, Campbell-Lendrum DH, Corval6n CF, Ebi KL, Githeko A, Scheraga JD, et al. Climate change and human health: risks and responses. World Health Organization; 2003.
32. Towers S, Chowell G, Hameed R, Jastrebski M, Khan M, Meeks J, Mubayi A, Harris G. Climate change and influenza: the likelihood of early and severe influenza seasons following warmer than average winters. PLoS currents. 2013;5. doi:10.1371/currents.flu.3679b56a3a5313dc7c043fb944c6f138
33. Curseu D, Popa M, Sirbu D, Stoian I. Potential impact of climate change on pandemic influenza risk. InGlobal warming 2010;643-657. Springer, Boston, MA. doi:10.1007/978-1-4419-1017-2_45
34. Krauss S, Walker D, Pryor SP, Niles L, Chenghong LI, Hinshaw VS, et al. Influenza A viruses of migrating wild aquatic birds in North America. Vector-Borne & Zoonotic Diseases. 2004;4(3):177-89. doi:10.1089/vbz.2004.4.177
35. Both C, Visser ME. The effect of climate change on the correlation between avian life-history traits. Global Change Biology. 2005;11(10):1606-13. doi:10.1111/j.1365-2486.2005.01038.x
36. Roche X, Fredrick K, Kamata A, Okuthe S, Kone P, Wiersma L,et al. 2016–2018 Spread of H5N8 highly pathogenic avian influenza (HPAI) in sub-Saharan Africa. 2018;12.
37. Sims L, Harder TC, Brown IH, Gaidet N, Belot G, von Dobschuetz S, et al. Highly pathogenic H5 avian influenza in 2016 and early 2017-observations and future perspectives. Focus on 11, 2017.
38. Napp S, Majy N, S6nchez-Gynzalez R, Vergara-Alert J. Emergence and spread of highly pathogenic avian influenza A (H5N8) in Europe in 2016-2017. Transboundary and Emerging Diseases. 2018;65(5):1217-26. doi:10.1111/tbed.12861
39. Laguipo ABB. NEWS MEDICAL LIFE SCIENCES. https://www.news-medical.net/amp/health/What-is-the-Difference-Between-COVI-19-and-the-Flu.aspx. 2020. Accessed July 27, 2020.
40. Biello D. Scientific American. https://www.scientificamerican.com/article/twelve-diseases-climate-change-may-make-worse/. 2008. 2020 July.
41. Ramin B. Slums, climate change and human health in sub-Saharan Africa. Bulletin of the World Health Organization 2009;87:886. doi: 10.2471/BLT.09.073445
42. Giordano M, Bassini E. Climate Change and Africa's Future. Hoover Institution. https://www.hoover.org/research/climate-change-and-africas-future. 2019.
43. US: Environmental Protection Agency. https://www.epa.gov/climate-indicators/greenhouse-gases. 2020. Accessed 2020 July.
44. Lackner M, Chen WY, Suzuki T. Introduction to climate change mitigation. Handbook of Climate Change Mitigation. 2012;1-9. doi:10.1007/978-1-4419-7991-9_1
45. Climate change mitigation. https://www.oecd.org/environment/cc/41751042.pdf. OECD; 2008.
46. Owusu PA, Asumadu-Sarkodie S. A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Engineering. 2016;3(1):1167990. doi:10.1080/23311916.2016.1167990
47. Kwan SC, Hashim JH. A review on co-benefits of mass public transportation in climate change mitigation. Sustainable Cities and Society. 2016;22:11-8. doi:10.1016/j.scs.2016.01.004
48. Scialabba NE, Mьller-Lindenlauf M. Organic agriculture and climate change. Renewable Agriculture and Food Systems. 2010;25(2):158-69. doi:10.1017/S1742170510000116
49. Fischer C, Newell RG. Environmental and technology policies for climate mitigation. Journal of environmental economics and management. 2008;55(2):142-62. doi:10.1016/j.jeem.2007.11.001
50. Crooks S, Herr D, Tamelander J, Laffoley D, Vandever J. Mitigating climate change through restoration and management of coastal wetlands and near-shore marine ecosystems: challenges and opportunities. 2011.
51. Rafaj P, Schupp W, Russ P, Heyes C, Amann M. Co-benefits of post-2012 global climate mitigation policies. Mitigation and Adaptation Strategies for Global Change. 2013;18(6):801-24. doi:10.1007/s11027-012-9390-6
52. Hirve S, Newman LP, Paget J, Azziz-Baumgartner E, Fitzner J, Bhat N, Vandemaele K, et al. Influenza seasonality in the tropics and subtropics–when to vaccinate?. PloS one. 2016;11(4):e0153003. doi:10.1371/journal.pone.0153003. eCollection 2016
53. The Paris Agreement on Climate Change. Natural Resources Defense Council, IB: 17-11-A. 2017;1-4.
54. Haines A, McMichael AJ, Smith KR, Roberts I, Woodcock J, Markandya A, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. The lancet. 2009;374(9707):2104-14. doi:10.1016/S0140-6736(09)61759-1
55. World Health Organization. Global health risks: mortality and burden of disease attributable to selected major risks. World Health Organization; 2009. https://apps.who.int/iris/bitstream/handle/10665/44203/9789241563871_eng.pdf
56. Smith K, Woodward A, Campbell-Lendrum D, Chadee D, Honda Y, Liu Q, et al. Human health: impacts, adaptation, and co-benefits. InClimate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. 1 ed. Cambridge UK : Cambridge University Press. Cambridge University Press. 2014;709-754.
57. Walpole SC, Rasanathan K, Campbell-Lendrum D. Natural and unnatural synergies: climate change policy and health equity. Bulletin of the World Health Organization. 2009;87:799-801. doi:10.2471/BLT.09.067116
58. Nhamo G, Muchuru S. Climate adaptation in the public health sector in Africa: Evidence from United Nations Framework convention on climate change national communications. Jamb6: Journal of Disaster Risk Studies. 2019;11(1):1-0. doi:10.4102/jamba.v11i1.644
59. Fox M, Zuidema C, Bauman B, Burke T, Sheehan M. Integrating public health into climate change policy and planning: state of practice update. International journal of environmental research and public health. 2019;16(18):3232. doi:10.3390/ijerph16183232
60. Ford JD. Indigenous health and climate change. American journal of public health. 2012;102(7):1260-6. doi:10.2105/AJPH.2012.300752