Book Chapter: Climate Change Epidemiology

Arindam Basu , Dr. Nitish Dogra , and nitish.dogra

Abstract

The goal of this chapter is to present the key principles of Epidemiology that can be used to interpret, describe, and analyse the health effects of climate change. Epidemiology refers to the study of the distribution and determinants of health related states and use of this knowledge to bring about improvements in health states.

Introduction

Since the beginning of the industrial era, a continual and progressive increase in the emission of combustion by-products and chemicals, including carbon dioxide, methane, oxides of nitrogen and sulphur, and other chemicals have occurred and they have accumulated in the atmosphere. In turn, these gases in the upper layers of the earth's atmosphere have trapped heat, reflected them back to earth's surface, in this process, their accumulation in the atmosphere have led to a corresponding rise in Earth's temperature. This phenomenon is referred to as "Global Warming". Global warming has led to melting of polar ice caps, increased carbon dioxide in the earth's atmosphere has led to acidification of the oceans, the melting of ice has led to increased volume of water in the ocean and altered salinity, and increased frequency of hurricanes over this time period – all these combined to produce an alteration in the Earth's climate since the industrial era Campbell-Lendrum, Corvalán, and Neira (2007)

Climate change is thus manifested in changing patterns of weather, world-wide melting of polar ice caps, loss of sea-ice, retreat of glaciers, and changing patterns of rainfall and humidity. These cascades of events are interconnected and have led to rise in sea levels, flooding of coastal areas, changes in the wind patterns, increased frequency of storm surges and hurricanes, loss of coral reefs, altered ocean salinity, abnormal rainfall patterns, with loss and migration of marine flora and fauna Xun, Khan, Michael, and Vineis (2010).

These phenomena have affected health of exposed populations in different ways. Increased temperature and humidity have resulted in worldwide changes in frequency of heat stress-related disorders and increased incidence of microbial and parasitic infections Pinkerton and Rom (2013). Changes in weather conditions, increased rainfall, changes in ocean salinity and migration of marine flora and fauna, loss of natural habitats, and crop failures have resulted in mass malnutrition; flooding of coastal areas lead to shifting human habitats, mass migration of affected populations and force them to relocate (??citation). In turn, these lead to new patterns of population health effects ranging from emergent patterns of microbial and parasitic diseases, nutritional and behavioural disorders, conflicts, and resultant loss of social well-being for populations Smith, Woodward, and Campbell-Lendrum (2011). In summary, heat-related diseases, infectious and microbial diseases, nutritional disorders, social conflicts, diseases attributed to poverty and stress are increasingly associated with climate change as an exposure variable. Given the nature of climate change as a "phenomenon", studying these associations using current tools and analytical strategies in epidemiology can pose a challenge.

Epidemiology is a body of knowledge of the study of the distribution and determinants of various health related states in populations Porta, Greenland, Hernán, dos Santos Silva, and Last (2014). Epidemiological principles can be used to predict future health states of populations. Study of climate change as an exposure of interest belongs to environmental epidemiology – that domain of epidemiology where environment is considered an exposure. Climate change is an environmental phenomenon; yet in applying principles of epidemiology to analyse and interpret health effects of climate change, one needs to consider different disciplines – these include meteorology and disasters, health services research, and clinical epidemiological studies as increasing temperatures across the world have resulted in different phenomena that are studied as triggers and exposure variables as well in considering health effects of climate change.

The epidemiology of climate change is multidisciplinary by nature. For example, global warming has resulted in increased frequency and intensity of hurricanes and floods, one can argue that associated epidemiological studies can be discussed under climate change or they could be categorised as studies of disaster epidemiology. Also as changing climate affects populations in different aspects (physical health, behavioural disorders, and social conditions such as mass migration, and conflicts), in using epidemiological principles to study health effects due to climate change, all these aspects need to be taken into consideration.

Overview of Epidemiological Study designs

"Epidemiology" is a combination of three fractions (*Epi* = upon, *demo* = people, and *logos* = study), from an etymological point of view then, it is the study of every phenomenon that affects populations. More formally, the definition of Epidemiology as mentioned in the Dictionary of Epidemiology is as follows:

> The study of the occurrence and distribution of health-related events, and processes in specified populations, including the study of determinants influencing such processes, and the application of this knowledge to control relevant health problems. ... Epidemiology is much more than a branch of medicine treating of epidemics. Epidemiology may also study disease in populations of animals and plants Porta et al. (2014)

This definition highlights three components of Epidemiology that can be considered in studying climate change related health events. The first component refers to the role of **descriptive epidemiology**, epidemiology of studying of disease patterns in terms of their distribution in time and space (temporal and spatial distribution). Public health surveillance is an epidemiological activity where cases of diseases or health related states are observed, recorded, and analysed in terms of how they are spread over time and space. These data are then used for planning health care planning. Campbell-Lendrum et.al. (2006) considers public health surveillance is essential in studying health effects of climate change for three related related reasons: first, health effects such as infectious disease outbreaks attributable to climate shifts can be rapid and therefore it is important to keep accurate records, second, climate change results in increased movement and contact between humans, pathogens and reservoirs, and third, human and animal disease outbreak monitoring need to be integrated with environmental monitoring, indicating need for the emergence of an integrative concept of planetary health Campbell-Lendrum et al. (2007); Woodward and Scheraga (2003) .

The second component is that of **analytical epidemiology** – epidemiology of investigating cause and effect associations between exposure and health outcomes – in unravelling the cause and effect association between the downstream effects of climate changes characterised by increased temperature, humidity, pathogens, social situations brought about by adverse weather events and defined health states. McMichael (2006) has argued that some of the causal pathways that link the downstream effects of climate change (for example heat stress and deaths) are better represented or have become uncontentious in the literature over several decades, while others (for example more complex pathways that link climate change related social changes and changes in the social determinants of health) are more contentious and are less studied. Also, not all health effects are harmful: increased global warming will lead to milder winters in higher latitudes of Northern and Southern Hemispheres leading to much less deaths due to cold related conditions, and likewise, hotter and drier conditions in some of the subtropical regions in the world might lead to lower breeding of mosquitoes due to adverse climatic conditions McMichael, Woodruff, and Hales (2006).

The third component of Epidemiology is its use in real world applications and policy making – the field of **applied epidemiology** and in translational research – where knowledge obtained from surveillance systems and analytical study designs such as case control and cohort studies are applied to influence health policy, public health decision making, and programme planning. In climate change literature, such applications are in examining and reducing vulnerability of communities to climate change either through adaptation or mitigation. Vulnerability refers to the propensity of suffering adverse health effects for people exposed to conditions of climate change. Here, "adaptation" refers to adjustment to the adverse climate exposure so as to minimise adverse heath effects. For humans, this process seeks to moderate or avoid harm or exploit beneficial opportunities; mitigation refers to the process of human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs) by any means Allwood, Bosetti, Dubash, Gomez-Echeverri, and von Stechow (2014). Analytical epidemiological studies can provide information about the predisposing features of what make communities vulnerable to the effects of climate change; equally, such studies can also provide effectiveness of interventions that will help communities to better adapt to and mitigate the effects of climate change.

Key Measures and Epidemiological Study designs

In epidemiological studies, measurement of exposure and health outcomes is the key. Epidemiologists begin with observation of health phenomena. These observations are in the form of describing the health related states and the association between specific exposure and health related states. For example, Andersen et.al. (2012) measured annual average concentration of oxides of nitrogen as an exposure variable and proxy measure for air pollutants in their study on the association between air pollution and asthma related hospitalisations Andersen et al. (2012).

In order to find associations between an exposure and a health outcome, epidemiologists may propose more than one theories; then, based on each theory, they state specific hypotheses using measurable attributes of exposure and outcome. These hypotheses are in the form of predictive statements and these statements form the basis of further data collection to refute null hypotheses. When the data refute the null hypothesis of no association, the theory is accepted as the best fit between data and the model.

Epidemiologists design studies on individuals to collect data, or they collect data from administrative and other databases where data are stored in aggregated format. Prevalence refers to the proportion of individuals in a population with the specified health effect; incidence refers to the extent of new cases in a specified population over a specified period of time. The denominator in prevalence estimates is the total number of individuals and the denominator in incidence is person-years, referred to as the product of follow up time period and population studied (person-years). A thousand person-years would be 1000 individuals followed up over one year; this figure would be equivalent of 100 individuals followed up over 10 years, or 200 individuals followed up over five years. Under steady state conditions, i.e., where the rate at which individuals contract a disease roughly equate the rate at which the individuals leave the disease state (i.e., they either recover or die), prevalence of the disease equals the product of incidence rate and the duration of the disease state. Prevalence estimates of diseases are best obtained from cross-sectional surveys and incidence rates are best obtained from cohort studies.

Prevalence and incidence are measures of disease occurrence, while relative risk estimates (rate ratios, odds ratios, standardised mortality and morbidity ratios and hazard ratios) are measures of exposure-disease associations. Rate Ratio refers to the ratio of the incidence rates of disease occurrence among exposed and unexposed. Odds Ratio (OR) is a measure of the likelihood of exposure between those with the disease and those without the disease of interest. Cohort studies provide information on incidence rates and case control or cross sectional studies provide information on odds ratios.

Standardized mortality or morbidity ratios (SMR) refer to the ratio of the total number of individuals with a disease between two different populations; these populations structures vary based on a specified criterion such as age, gender, or another parameter. Epidemiologists use standardised mortality or morbidity ratios to compare occurrence of diseases across different geographical regions, across populations, and across time points. In each of these situations, the population have different distributions of age, gender, or other parameters of interest. Fernandez et.al. (2008) tested the association between meteorological variables and asthma mortality in Cuba using this strategy. They correlated spatial meteorological data and standardised mortality ratios from Asthma in these regions between 1989-2003 Fernández, Barcala, Ortíz, and Núñez (2008).

Hazards Ratio (HR) refers to the ratio of likelihoods of health effects from an exposure over time. Wang et.al. (2013) investigated whether exposure to heatwave would lead to increased preterm birth; they conducted a population based study of 50, 848 spontaneous births in Brisbane between 2000-2010. They obtained daily data on pregnancy outcomes, meteorological factors and air pollutants between 1999-2010. For this birth cohort, they used survival analysis to study the effect of meteorological factors on pre-term births and reported hazards ratio for pre-term births for women who experienced heat waves as opposed to those who did not experience heat wave Wang, Williams, Guo, Pan, and Tong (2013). Thus, depending on different types of study designs, Environmental epidemiologists use different measures of association between exposures of interest and health outcomes. In particular, they use associative measures to indicate strengths of association for causal linkages.

Cause and Effect in Environmental Epidemiology and Climate studies

Analytical epidemiology is about establishment of the cause and effect assoiciation between an exposure and a health outcome: the first step is to test a valid association. The second step is to establish or examine the nature of such an association – whether it is one of cause and effect. Valid association is established on the basis of three issues:

1. The researcher must rule out the play of chance. – The researcher must ensure that the association between the exposure and the disease outcome cannot be due to chance; prior to the study, the rate of type I and type II errors should be fixed; alpha error is set at 5% and beta error is set at 20%. These are then used to estimate an appropriate sample size for conducting the epidemiological study. Following completion of the study, at the stage of data analysis, the researcher reports the likelihood of the study results to occur under conditions of null hypothesis. This likelihood is expressed in the form of p-values. Besides reporting the p-value, the researcher also reports the 95% confidence interval. The 95% confidence interval around the point estimate of association indicates the range within which the true value of the association would lie. If the 95% confidence interval straddles 1 (for ratio based measures) or 0 (for effect measures of risk difference) then the study would have failed to refute the null hypothesis, and hence a play of chance in the association between the exposure and the outcome cannot be ruled out.
2. The researcher must ensure that the study is free of biases. – The term bias refers to a systematic error in the conduct of the study. For individual data based observational epidemiological studies, biases can arise when the two comparable groups differ significantly between each other in some ways, either in the way they were selected (selection bias), or they differ in which they respond to the data collection process (response bias). Based on the way the groups are compared, the biases can be random or non-random. If the biases are random, then the risk estimates would deviate towards the null value; if the biases are non-random, then the risk estimates can be either away from the null estimate or towards the null estimate. Biases can be eliminated only at the stage of planning the study; nothing can be done to mitigate the effects of biases following data collection or at the stage of data analysis.
3. The researcher must control for confounding variables. – Confounding variables refer to those variables that are associated both with the exposure variable and the outcome variable yet the variable should not come in the causal pathway. In the context of studying health effects of climate change, age, gender, and socio-economic status would be examples of variables that would confound the effect of

the climate change variables. For example, if a researcher is to study the effect of heat waves on mortality, then age (extremes of age) or socioeconomic status or job status (people who cannot afford climate control technology or who have to work outdoors) would need to be considered as confounding variables. These variables can be controlled for in different ways. In case control studies, individuals with and without the health conditions can be matched on potential confounding variables; studies can be conducted where the participants would be restricted to specific age groups, or gender; and following collection of data, researchers can conduct multivariate data analysis and modelling to test for the effects of potential confounding variables.

Ruling out the play of chance, controlling for confounding variables and conducting a study free of biases ensure that the study is internally valid and that the association is a "real" association. However, a valid association does not imply that the nature of this association is causal as well. Rothman (2005) has discussed the notion of cause and effect in epidemiology using the concepts of necessary and sufficient causal models; a sufficient causal model is one where different causal components would come to "play" to complete the circle of causation Rothman and Greenland (2005). The components of such causal models can act together or they can act in tandem. When we think of climate change in a causal framework where remote events lead to more proximal exposures and these in turn lead to health effects, this is a helpful conceptual model in epidemiological studies that investigate health effects of climate change. However, in deciding whether the nature of the association is one of cause and effect, Sir Austin Bradford Hill (1965) proposed nine viewpoints as follows Hill, AB (1965):

1. Strength of Association. – Hill argued that if some factor had a strong association with an outcome, then that would imply that competing factors as unlikely to be causes. He nevertheless did not rule out that there could be other factors with small levels of association could be causal, although he considered that highly unlikely.
2. Consistency of Association. – Is this association observed in different situations and populations?
3. Specificity of Association. – Is there a one-on-one correspondence between the exposure and the disease?
4. Temporality. – this is a necessary condition for causal inference, where the cause must precede the effect.
5. Biological Gradient. – this is also referred to as dose response gradient, where as the dosage of the exposure increases, a corresponding increase in the effect occurs as well.
6. Plausibility. – Would it be possible to identify some physiological or other biological mechanism as to what is known under the current knowledge that might explain the cause and effect association?
7. Coherence. – Is a cause and effect association coherent under the current state of knowledge?
8. Experimental Evidence. In clinical settings, or in clinical evidence, a randomised controlled trial is a close approximation.
9. Analogy. – Are there other comparable instances where these can be supported? For issues around climate change related studies, if one were to study one climate change related phenomenon to be linked to a specific health outcome, then another comparable climate change related event might be used as an analogy. For example, an indicator of climate change is increased humidity; another is increased precipitation. Both situations lead to specific types of infectious diseases. If we believe that the antecedent factor that led to increased humidity over time and increased precipitation over time would be climate change or global warming, then the disease association as "causal" would be supported.

In epidemiology, these notions of cause and effect and internally valid associations are tested using a range of study designs where the exposure is measured and then correlated with measures of occurrence of disease conditions (or other health states). Study designs in environmental epidemiology, where climate change related health effects are studied, do not involve experiments or clinical studies such as randomised controlled trials.

Not all epidemiological study designs are designed to obtain cause and effect relationships between an exposure and an outcome. Case series are descriptive studies were a number of “cases” of a disease conditions or health states are described and tallied. This is the principle of surveillance. Cross sectional studies are conducted in order to ascertain the prevalence of a disease or a risk factor. In cross sectional surveys, data from a sample of individuals are obtained on their exposure and outcome at the same time. These studies enable the epidemiologists to frame further studies or frame hypotheses that can be tested in other study designs where comparable groups of people are assembled and different types of information are obtained from them.

Observational epidemiological study designs aimed at testing causality include cohort and case-control studies. When sampling of individuals are conducted on the basis of their exposure status (some individuals are exposed to the risk factor under study and others are not exposed and all individuals in the beginning of the study are free of the health outcome under study), and the individuals are followed through in time to study the emergence of the disease or health state in each group, such a study is referred to as cohort study. The groups of individuals assembled in this way are referred to as “cohorts”. The measure of association in cohort studies are rate ratio or relative risk where incidence of disease among the exposed is compared with the incidence of disease 9or rate of occurrence of the disease among the non-exposed. When individuals are sampled on the basis of their health states (either diseases or non-diseased), this study is referred to as case control study. Cases in case control study are those who have already developed the disease under investigation, and controls are those individuals who have not developed the disease or free from the disaease and for everyone in the study, their exposure are compared. The measure of association for case control studies is Odds Ratio (OR) where odds of exposure are compared between those who have the disease or cases and controls.

In summary, epidemiology is a study of disease occurrences and causes or determinants of diseases in populations. The measures of distribution of diseases are reporred in the form of inicidenc and prevalence, and the measures of association of diseases and exposures in the population are reported in the form of different measures of relative risk. When incidences are compared, this metric is referred to as relative risk or rate ratio; when odds of exposure are compared, this is referred to as Odds Ratio (as in Case contro scontrol stdies). These are study designs, where individual data are analysed. Otehr forms of studies use data n aggregated format or data from administrative databases. Such studies are referred to as ecological studies. In ecological studies, aggregated data ara aare are analysed for both xposure and outcomes. Studies on the association beween air pollution and asthma are ecological studies where data on air quality and asthma related hospitalisations are obtained in aggregated data format. A caveat for this kind of studies is that, one cannot infer implications for individuals from the results of studies where the data are collected in aggregate format (ecological fallacy).

Challenges in studying health effects related to climate change

Epidemiological studies are conducted in populations and they yield information on individual exposure and health outcomes. However, this also implies that in order to assess cause and effect associations, it is necessary to have individual variations in the exposure and health outcomes. Cohort or case control studies depend on collecting data from individuals and local variations in the pattern of exposure. In cohort studies, scientists would classify individuals into exposed and non-exposed groups and would follow them through over time to study emergence of disease conditions or health states that were absent in the beginning of the study. In case control studies, scientists would consider people with and without diseases and would then use data collection to ascertain likelihood of exposure. While these study designs provide insights into individual exposure and outcomes, these study designs are of limited use when it comes to study parameters of climate change, because the variations are in planetary scales or in scales over hundreds and thousands of years.

On the other hand, study designs such as ecological study designs where aggregated measurements are used for comparing exposures and outcomes, have limited applications in individual level decision making. But these study designs are suited to study time dependent or space dependent changes in both exposures and outcomes. Study designs with large scale data (“big data”) are also suited to study planetary scale variability. While these studies based on aggregated data are useful for studying associations between climate change parameters, the results are not applicable to individual situations. In other words, knowing temperature changes are associated increase mortality or hospitalisations would not enable us to deduce that on a particular hot day or weather conditions would also predict an individual with a higher risk of death or hospitalisation. Such inference is referred to as ecological fallacy and indicates that it is impossible to extrapolate results of ecological studies to individual cases Seiler and Alvarez (2000).

While it is impossible to infer individual causal risk associations from aggregated measurements and therefore from the results of epidemiological studies, scientists have studied the health effects of climate change in other ways. For example, Martinez-Urtaza (2010) conducted a review of the outbreaks of the vibrio parahaemolyticus and vibrio vulnificus in different parts of the world and suggest that data from satellite imagery have provided oceanographic data of the spread of the warmer ocean water to temperate and closer to the poles and El Nino phenomena have contributed to the emergence of virulent strains of vibrio parahaemolyticus and vibrio vulnificus and new epidemics and endemic regions have appeared in regions of the world that were not known previously Martinez-Urtaza, Bowers, Trinanes, and DePaola (2010). This approach provides an indirect connection to the causal linkage between climate change and specific disease or disease outbreaks. In an investigation of gastroenteritis outbreak in a cruise ship in Alaska in 2004, McLaughlin et.al. (2005) conducted a retrospective cohort study of the passengers in the cruise ship where the gastroenteritis outbreak occured and found that consumption of raw oysters was predictor of illness. The investigators suggested that the rising temperature of the ocean water contributed to this outbreak McLaughlin et al. (2005). While the investigators conducted a retrospective cohort study to ascertain the cause of the illness in the cruise-ship passengers, the real cause could be traced back to the phenomenon of global warming and climate change as this investigation would reveal that the northernmost documented source of the oysters spread by about 1000 kilometers and this unusual phenomenon might be explained by an unusual warm ocean water. According to AR5 report of the IPCC, there are three mechanisms by which cilmate change will exert effects on health: direct impacts of climate change, indirect impacts, and human factor mediated changes. Direct impacts include increased temperature, increased risks of drought and flood, heavy rainfall in places, increased risk of hurricanes and storms; indirect effects include increase in vector species such as mosquitoes, crop failure, and other effects that will result in response to climate related changes; and societal changes, for example, conflicts, migration of people from one region to another Smith et al. (2011). Epidemiological studies have addressed each of these factors on the association with specified health outcomes.

Summary

Epidemiology is the study of the distribution and determinants of health related states in populations and use of such of knowledge in disease prevention and health promotion. Nancy Krieger (1999) argued if epidemiology should be referred to as the basic science of public health Krieger (1999). Climate change refers to a series of changes that have occurred in the planet as a result of worldwide warming brought about by human activities (and continues unabated), accelerated since the time of industrial revolution due to increased accumulation of greenhouse gases. Increased temperature, increased humidity, increased precipitation, and increased frequency of natural disasters and hurricanes have resulted a role of epidemiology to systematically investigate the health effects associated with these phenomena. However, traditional approaches of epidemiology with its emphasis on individual exposure and individually assessed health effects have limited applicability when applied to planetary scale health effects brought about by climate related changes. Hence new approaches should be sought within the field of epidemiology to assess the health effects of climate change: these include refinement in ecological studies and linking model based assessments of climate change and global warming to specific antecedent events such as warming, increased temperature, and natural disasters and associated health effects on a mass scale.

References

Allwood, J. M., Bosetti, V., Dubash, N. K., Gomez-Echeverri, L., & von Stechow, C. (2014, nov). Glossary. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, K. Kadner, & J. C. Minx (Eds.), *Climate change 2014:* (pp. 1–34). Cambridge, UK.

Andersen, Z. J., Bønnelykke, K., Hvidberg, M., Jensen, S. S., Ketzel, M., Loft, S., . . . Raaschou-Nielsen, O. (2012). Long-term exposure to air pollution and asthma hospitalisations in older adults: a cohort study. *Thorax*, *67*(1), 6–11.

Campbell-Lendrum, D., Corvalán, C., & Neira, M. (2007, mar). Global climate change: implications for international public health policy. *Bulletin of the World Health Organization*, *85*(3), 235–237.

Fernández, S. J. V., Barcala, F. J. G., Ortíz, D. F., & Núñez, H. M. F. (2008). Epidemiology of Asthma Mortality in Cuba and its Relation to Climate, 1989 to 2003. *MEDICC review*, *10*(3), 24.

Hill, AB. (1965). The Environment and Disease: Association or Causation.

Krieger, N. (1999). Questioning epidemiology: objectivity, advocacy, and socially responsible science. *American Journal of Public Health*, *89*(8), 1151–1153.

Martinez-Urtaza, J., Bowers, J. C., Trinanes, J., & DePaola, A. (2010, aug). Climate anomalies and the increasing risk of Vibrio parahaemolyticus and Vibrio vulnificus illnesses. *Food Research International*, *43*(7), 1780–1790.

McLaughlin, J. B., DePaola, A., Bopp, C. A., Martinek, K. A., Napolilli, N. P., Allison, C. G., . . . Middaugh, J. P. (2005, oct). Outbreak of Vibrio parahaemolyticusGastroenteritis Associated with Alaskan Oysters. *New England Journal of Medicine*, *353*(14), 1463–1470.

McMichael, A. J., Woodruff, R. E., & Hales, S. (2006, mar). Climate change and human health: present and future risks. *The Lancet*, *367*(9513), 859–869.

Pinkerton, K. E., & Rom, W. N. (2013). *Global Climate Change and Public Health.* Springer Science & Business Media.

Porta, M., Greenland, S., Hernán, M., dos Santos Silva, I., & Last, J. M. (2014). *A Dictionary of Epidemiology.* Oxford University Press.

Rothman, K. J., & Greenland, S. (2005, jul). Causation and Causal Inference in Epidemiology. *American Journal of Public Health*, *95*(S1), S144–S150.

Seiler, F. A., & Alvarez, J. L. (2000, nov). Is the "Ecological Fallacy" a Fallacy? *Human and Ecological Risk Assessment: An International Journal*, *6*(6), 921–941. Retrieved from https://doi.org/10.1080%2F10807030091124365 doi: 10.1080/10807030091124365

Smith, K., Woodward, A., & Campbell-Lendrum, D. (2011, oct). Human health: impacts, adaptation, and co-benefits . In C. B. Field, V. R. Barros, & D. J. Dokken (Eds.), *Climate change impacts, adaptation, and vulnerability.* (pp. 1–46).

Wang, J., Williams, G., Guo, Y., Pan, X., & Tong, S. (2013). Maternal exposure to heatwave and preterm birth in Brisbane, Australia. *BJOG: An International Journal of Obstetrics & Gynaecology*, *120*(13), 1631–1641.

Woodward, A., & Scheraga, J. (2003). Looking to the future: challenges for scientists studying climate change and health. *Climate Change and Human Health: Risks and Responses (McMichael AJ, Campbell-Lendrum DH, Corvalan CF, Ebi KL, Githeko A, Scheraga JD, et al., eds). Geneva: World Health Organization*, *61*, 78.

Xun, W. W., Khan, A. E., Michael, E., & Vineis, P. (2010). Climate change epidemiology: methodological challenges. *International journal of public health*, *55*(2), 85–96.