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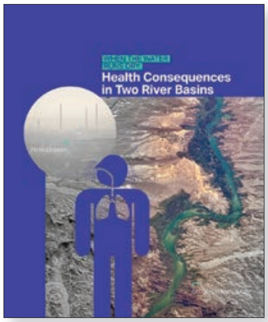

The Health-Related Consequences of Drought in the Po and Colorado River Basins

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Abstract **Global climate change will continue to expose more communities to drought, a prominent environmental health hazard. Droughts directly and indirectly affect the health of communities through reduced air and water quality, increased incidence of infectious disease, malnutrition, and mental illness. The Po River Basin region in Europe and the Colorado River Basin region in the U.S. illustrate how geography and policy affect the prevalence of health-related consequences of drought. Our study quantifies the relevant health-related consequences of drought in these two regions and identifies the most salient public health challenge in each region. The most salient risk in the Po River Basin is the heavy industry and natural geography that result in poor air quality. In the Colorado River Basin, the emerging disease coccidioidomycosis (Valley fever) poses the most salient risk. By identifying these prominent health-related consequences, public health practitioners and policymakers can more strategically target interventions and policies to reduce the health burden of drought.**

Keywords: drought, air quality, coccidioidomycosis (Valley fever), health consequences, Colorado River Basin (U.S.), Po River Basin (Italy)

Introduction

Global climate change threatens a variety of environmental resources, including water. Rising temperatures and altered weather patterns affect the volume of existing surface water, groundwater, and precipitation (Intergovernmental Panel on Climate Change [IPCC], 2023). Globally, climate change is expected to increase freshwater resources due to increased precipitation, runoff, river discharge, and flooding (Oki & Kanae, 2006). In some regions, however, weather variability compounded with higher temperatures will lead to periods of drought interspersed with flooding (IPCC, 2023). Currently, one half of the global population experiences water scarcity for at least part of the year (IPCC, 2023). As climate change persists, water availability will continue to decline, especially for those already living in water-scarce environments (Gosling & Arnell, 2016).

Water scarcity is associated with negative health outcomes, including reduced air quality, waterborne and vectorborne diseases, malnutrition, migration, and mental illness. Poor air quality causes and aggravates numerous conditions including upper respiratory tract infections, asthma, and cardiovascular disease (Li et al., 2023; Lippmann, 2020). Exposure to airborne pollutants also increases rates of diabetes mellitus and adverse birth outcomes (Feng et al., 2016). Drought inhibits the removal of airborne pollutants from the air via precipitation, alters the generation rate of pollutants such as ozone, and extends the suspension time of airborne particulates (Wang et al., 2017). Dry conditions also favor wildfires and the resuspension of soil, both of which are common sources of airborne pollutants (Bo et al., 2020; Šmejkalová & Brzezina, 2022). These mechanisms can increase concentrations of coarse particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), and nitrogen oxide despite reductions in anthropogenic emissions (Hu et al., 2019). Conversely, periods of high precipitation reduce concentrations of PM_{10} (Baltaci et al., 2019). Through these reductions in wet scavenging and changes in pollutant dynamics, the negative health consequences of air pollutants worsen during drought conditions and exemplify the direct consequences of drought on health.

Particulate matter often includes soil-residing pathogens such as *Coccidioides immitis* and *C. posadasii*, the causative agents of coccidioidomycosis (Valley fever). *Coccidioides* mycelia reside in the soil and produce spores that, when inhaled, cause fungal pneumonia in a variety of hosts such as humans, dogs, and aquatic mammals (Nguyen et al., 2013). Soil moisture provided by winter pre-

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FIGURE 1

The Po River Basin in Northern Italy

Source: Food and Agriculture Organization of the United Nations and Esri.

cipitation and El Niño–Southern Oscillations facilitates the growth of *Coccidioides* mycelia (Tobin et al., 2022; Weaver & Kolivras, 2018). Subsequent periods of high temperatures and drought then dry the soil, increasing the risk of soil disturbance and transmission (Head et al., 2022). Thus, within-year variability of precipitation increases the transmission of Valley fever, contributing to the public health burden of drought-related air pollution (Shriber et al., 2017).

In addition to reducing soil moisture, drought alters surface water availability, increasing the risk of chemical contamination. Drought-associated floods introduce nonpoint source nitrogen and phosphorus pollution via runoff (Bi et al., 2019). Similarly, groundwater depletion during droughts increases nitrate concentrations in private wells, which are a critical water infrastructure in rural communities (Levy et al., 2021). This nitrate contamination can result in inadequate blood oxygenation levels in infants and occasionally fatal methemoglobinemia (Maxwell, 2013). Drought-associated chemical contamination of surface and groundwater thus presents a severe public health threat, especially in rural areas.

Drought-driven declines in surface water availability also impact the ecology and epidemiology of mosquito-borne diseases. The most well-evidenced zoonotic disease associated with drought is West Nile virus (WNV) disease (Davis et al., 2018; Johnson & Sukhdeo, 2013; Paull et al., 2017; Ruiz et al., 2010). *Culex pipiens*—the main WNV vector in the U.S. and Italy—has a higher dehydration tolerance than most insects, including other mosquitoes; they can tolerate up to 40% water loss. This resistance to dehydration facilitates increased *Culex* populations following drought (Benoit & Denlinger, 2007). Furthermore, dehydration in *Culex* mosquitoes increases activity and biting rates, amplifying the risk of disease transmission (Hagan et al., 2018). These behaviors differentiate *Culex* mosquitoes from other vectors and facilitate the amplification of diseases vectored by *Culex* mosquitoes in drought conditions.

Vector–pathogen dynamics also facilitate the relationship between WNV and drought. The higher temperatures that often accompany drought increase WNV titers in mosquitoes, shorten WNV incubation time, and increase the amount of virus transmitted from vectors to hosts (Reisen et al., 2006). Similarly, higher temperatures increase mosquito WNV infection rates (Kilpatrick et al., 2008). Combined with the dehydration resistance and drought-time behavior of the *Culex* vector, WNV dynamics during drought facilitate the amplification of WNV transmission.

Drought also exacerbates poverty. Several social and economic determinants of health, including nutrition and migration, drive this complicated problem. Indeed, for already-impoverished groups living on the edge of subsistence, drought can bring additional distress, even devastation (Landes, 1999). Many agricultural communities depend on locally cultivated crops and livestock for nutritional content. When drought decreases crop yields, subsistence agriculturists face food insecurity (Brewis et al., 2020; Lieber et al., 2020). Decreased water availability also inhibits food preparation and safety while diverting income from food acquisition to water acquisition (Brewis et al., 2020). Through these mechanisms, drought increases short-term effects of malnutrition such as lower body mass, especially in children (Jankowska et al., 2012; Lieber et al., 2020). Long-term effects, such as child wasting or stunting, can also increase following drought periods (Hagos et al., 2014; Jankowska et al., 2012; Yeboah et al., 2022). While drought is often not the sole contributor to food insecurity and poverty, it does amplify existing challenges.

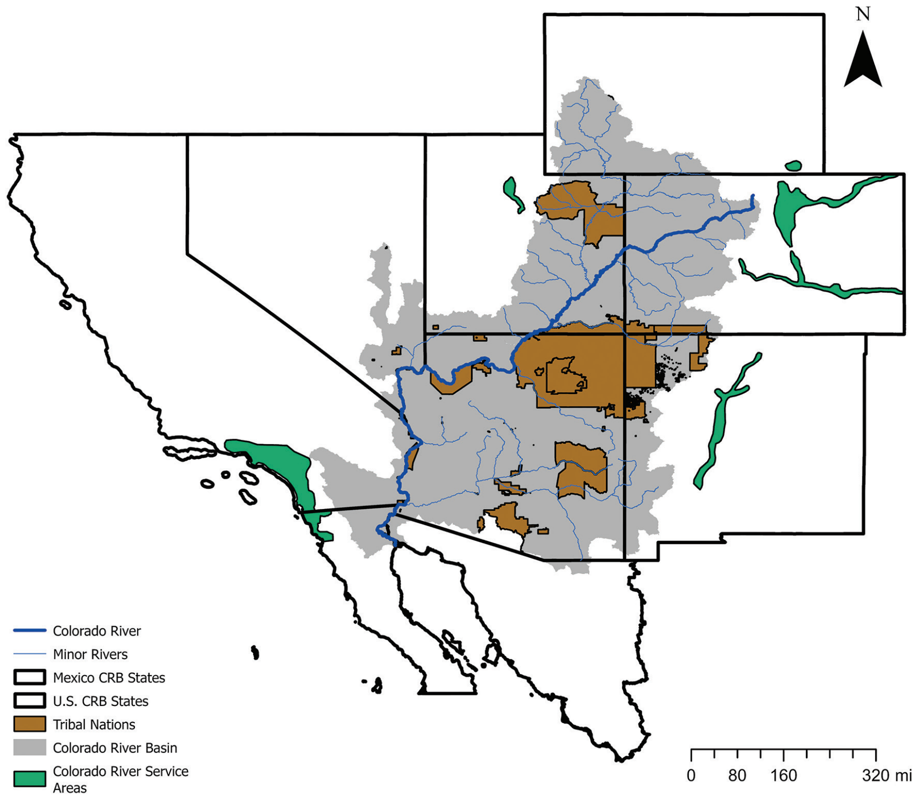
Drought poses numerous health-related and economic challenges that often induce internal (within-country) and external (between-country) migration. Typically, drought-related migration consists of men from rural, agricultural communities seeking alternative income sources in urban areas—areas that might also be experiencing drought-related health impacts (Defrance et al., 2023; Gray & Mueller, 2012). Migration as an adaptive strategy, however, is often a temporary last resort (Jülich, 2011). Drought-related migration is a contributor to global migration and accounted for 10% of the global increase in migration between 1970 and 2000 (Zaveri et al., 2021). Some subpopulations—notably women and the poor—are unable to migrate due to financial or other barriers and instead face other health-related challenges of drought (Borgomeo et al., 2021; Defrance et al., 2023; Gray & Mueller, 2012). Individuals who do migrate also experience a variety of negative health outcomes. Migrants, when not appropriately supported by the nation-state governments receiving them, face an increased risk of infectious diseases—notably, tuberculosis, AIDS, and waterborne and foodborne illnesses (Gushulak & MacPherson, 2007). Mental health challenges, including but not limited to depression, also persist in migrant communities (Bhugra, 2004).

Drought also affects the mental health of nonmigrant communities. Again, drought increases food insecurity, a risk factor for mental distress (Friel et al., 2014). Other stressors, including financial distress and social isolation, pose challenges (Sartore et al., 2008; Vins et al., 2015). Farmers and their families thus report increased stress and depression during droughts (Dean & Stain, 2010; Sartore et al., 2008; Vins et al., 2015). Drought-related mental health challenges can be so severe as to increase suicides, especially in rural men (Hanigan & Chaston, 2022). The culminating economic and health-related challenges of drought have severe consequences on rural mental health, compounding the public health burden of drought.

Our study examines the health-related consequences of drought in two regions, the Po River Basin (PRB) in Northern Italy and the Colorado River Basin (CRB) in the Western U.S. The 661-km (410-mi) Po River forms the 71,000 km^2 (27,000 mi^2) PRB, providing water for 17 million people in Italy and Switzerland (Figure 1). The 2,220-km (1,400-mi) Colorado River forms the 630,000 km^2 (240,000 mi^2) CRB, providing water for 40 million people across 7 states (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming), 30 federally recognized tribes, and Mexico (Figure 2). Both rivers are sourced largely from snowmelt, and as such are threatened by rising temperatures due to climate change. In the PRB, decreased precipitation and snowmelt, along with increased evapotranspiration (likely due to higher temperatures), have led to periodic drought conditions. Similarly, warming trends in the CRB have decreased snowpack, leading to a sustained drought since 2000.

FIGURE **2**

The Colorado River Basin (CRB) in the Southwestern United States



Source: Lincoln Institute of Land Policy.

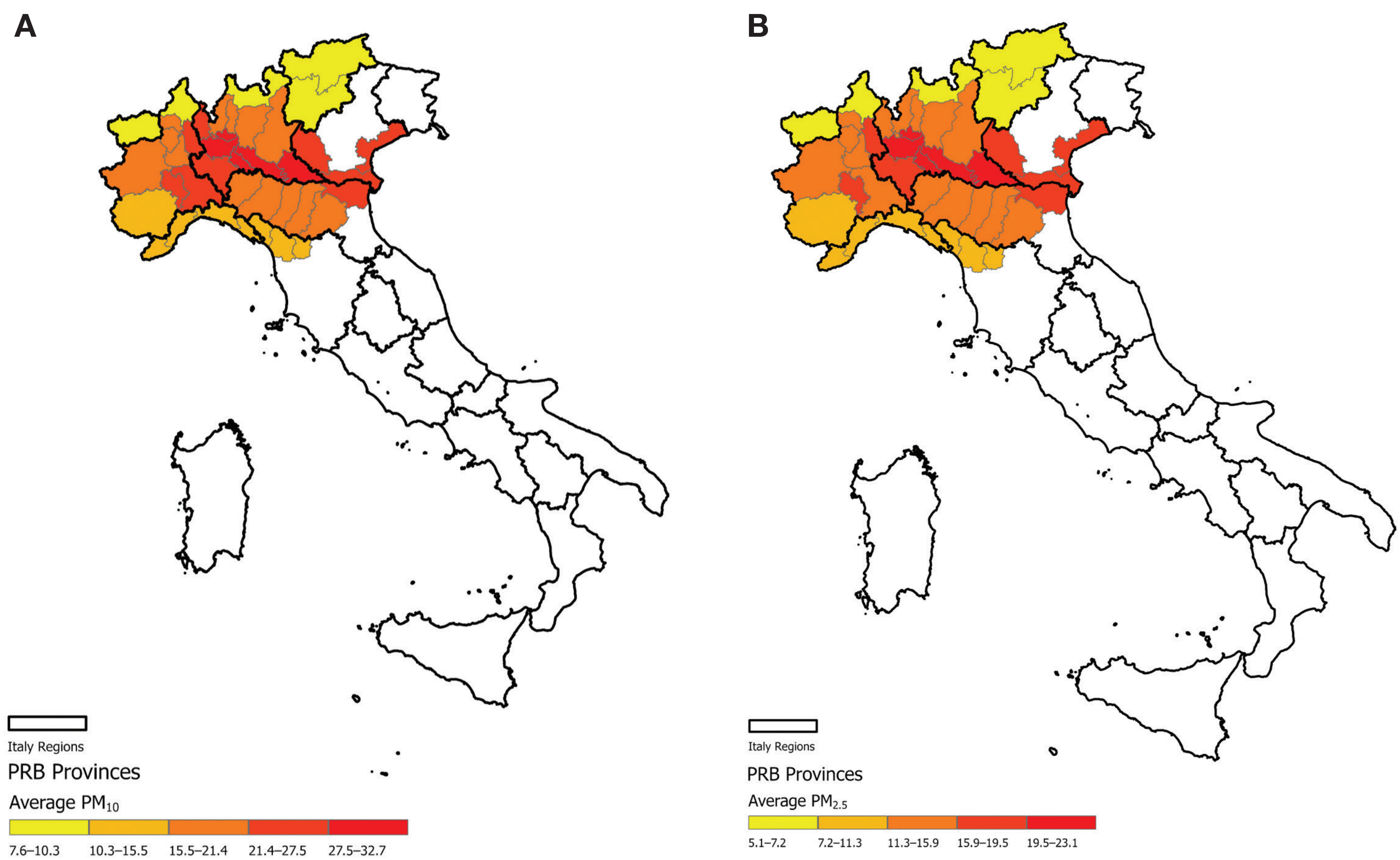
To prioritize avenues for public health and other policy interventions, we explore the severity of the potential health-related consequences of drought in both the PRB and the CRB. Additionally, we compare the severity of each consequence between both regions to demonstrate how geography and existing policies influence the degree to which droughts impact communities.

Methods

Our study examined the severity of PM_{10}, $PM_{2.5}$, coccidioidomycosis, groundwater nitrate infiltration, WNV, and relative poverty in the PRB and CRB. To assess these health-related consequences of drought, we used publicly available data sets. The 2013–2021 PM_{10} and $PM_{2.5}$ data from Italy originated from the European Environment Agency (2025a, 2025b), while the U.S. Environmental Protection Agency (2023) sourced the 2013–2022 U.S. data. The Arizona and California 2013–2022 county-level coccidioidomycosis data originated

FIGURE 3

Average A) PM_{10} and B) $PM_{2.5}$ Concentrations in the Po River Basin (PRB) From 2013–2021



from the California Department of Public Health (2024) and the Arizona Department of Health Services (2025), and state-level data for Nevada, New Mexico, Utah, and Wyoming were obtained from the Centers for Disease Control and Prevention (CDC, n.d.). The 2013–2021 groundwater nitrate concentrations from Italy are available from the European Environment Agency (2024), and the 2013–2022 U.S. data were sourced through the U.S. Water Quality Portal (National Water Quality Monitoring Council et al., 2021).

Additionally, the European Center for Disease Control (2024) and CDC (2025) provided the 2013–2022 WNV data. The relative poverty data for Italy originated from the Italian National Institute of Statistics (2023), while the U.S. Census Bureau (2023) sourced the CRB data. Once sourced, the data were cleaned, reformatted, analyzed, and visualized using RStudio (version 2024.04.0) and ArcGIS Pro (version 3.2.1, Esri Inc.). Figures were generated in RStudio using the ggplot2 package (Wickham, 2009). Maps generated in ArcGIS Pro used shapefiles from Esri, the Food and Agriculture Organization of the United Nations, and the Lincoln Institute of Land Policy.

Results

From 2013–2021, the PRB experienced an average PM_{10} concentration of 19.72 $\mu g/m^3$ and an average $PM_{2.5}$ concentration of 13.81 $\mu g/m^3$. Average PM_{10} concentrations ranged from 0 $\mu g/m^3$ to 47.3 $\mu g/m^3$ with an average minimum value of 7.5 $\mu g/m^3$ and an average maximum value of 33.7 $\mu g/m^3$. Average $PM_{2.5}$ concentrations ranged from 0 $\mu g/m^3$ to 35.6 $\mu g/m^3$ with an average minimum value of 4.4 $\mu g/m^3$ and an average maximum value of 24.6 $\mu g/m^3$. Figures 3 and 4 show the average pollutant concentrations in the PRB for the study period.

From 2013–2022, the CRB experienced an average PM_{10} concentration of 19.33 $\mu g/m^3$ and an average $PM_{2.5}$ concentration of 6.4 $\mu g/m^3$. Average PM_{10} concentrations ranged from 6.4 $\mu g/m^3$ to 120.3 $\mu g/m^3$ with an average minimum value of 12.3 $\mu g/m^3$ and an average maximum value of 29.6 $\mu g/m^3$. Average $PM_{2.5}$ concentrations ranged from 0.9 $\mu g/m^3$ to 30.5 $\mu g/m^3$ with an average minimum value of 4.3 $\mu g/m^3$ and an average maximum value of 8.7 $\mu g/m^3$. Figures 5 and 6 show the average pollutant concentrations in the CRB for the study period.

The CRB reported 90,861 cases of coccidioidomycosis with an average annual incidence of 43.47 cases per 100,000 residents. Pinal County, Arizona, reported the highest average incidence of 162.5 cases per 100,000 residents. Valley fever cases peaked in the CRB in 2021 with 12,901 cases and an incidence of 59.9 cases per 100,000 residents. Additionally, Valley fever case incidences ranged annually from 0 cases to 258.3 cases per 100,000 residents, with an average minimum incidence of 26.8 cases per 100,000 residents and an average maximum incidence of 68.2 cases per 100,000 residents. Figures 7 and 8 show the average incidence of Valley fever in the CRB during the study period.

From 2013–2021, PRB groundwater nitrate concentration averaged 24.2 mg/L. Nitrate concentrations ranged from 0.92 mg/L to 435.9 mg/L with an average minimum value of 14.9 mg/L and an average maximum value of 55.8 mg/L. PRB nitrate concentrations peaked in 2020, with an average concentration of 53.5 mg/L. Figure 9 shows the average nitrate concentrations in the PRB during the study period.

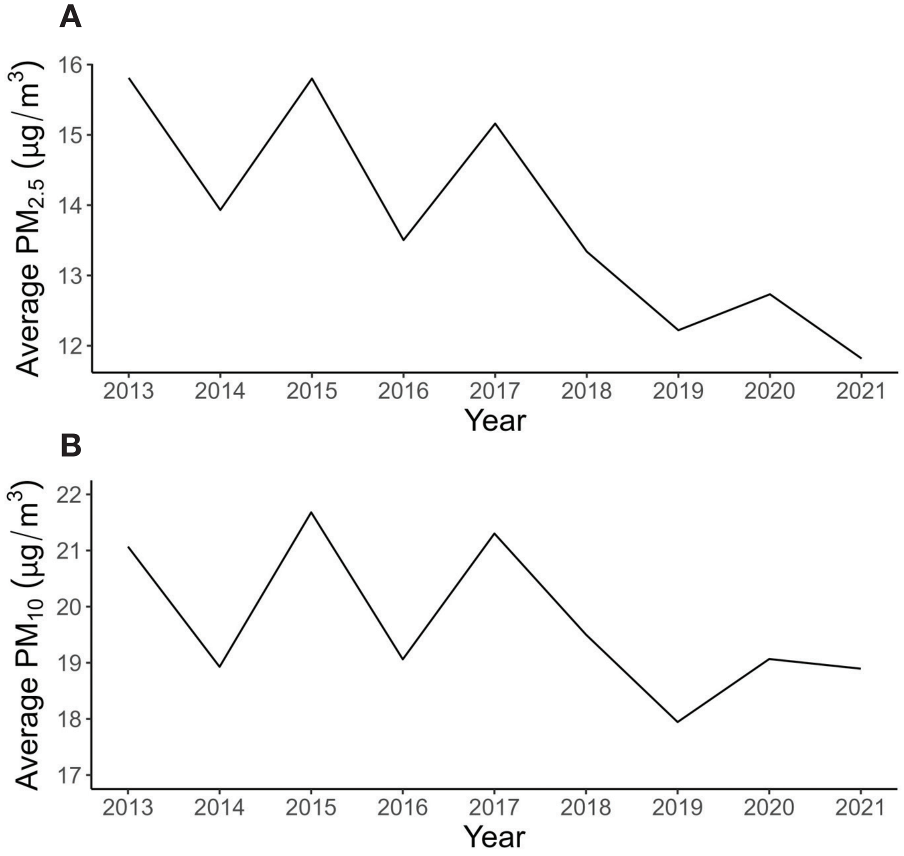
In the seven CRB states, groundwater nitrate concentrations averaged 88.2 mg/L. Nitrate concentrations ranged from 0.2 mg/L to 1,845.5 mg/L with an average minimum concentration of 85.6 mg/L and an average maximum concentration of 91.3 mg/L. CRB nitrate concentrations peaked in 2018, with an average concentration of 311.5 mg/L. Figure 10 shows the average nitrate concentrations in the CRB during the study period.

From 2013–2022, the PRB reported 1,182 cases of WNV for an average cumulative incidence of 8.3 cases per 100,000 residents, with Rovigo Province in Italy having the highest cumulative incidence of 40.5 cases per 100,000 residents. WNV cases peaked in 2018 and 2022 as the PRB reported 403 and 389 cases, respectively, corresponding to an average incidence of 3.1 cases per 100,000 residents in 2018 and 2022.

The CRB reported 4,155 cases of WNV between 2013 and 2022 for an average cumulative incidence of 33.4 cases per 100,000 residents. Delta County, Colorado, had the highest cumulative incidence with 368 cases per 100,000 residents over the study period. WNV cases peaked in 2021 as CRB counties reported 1,934 cases.

FIGURE **4**

Annual Average A) $PM_{2.5}$ and B) PM_{10} Concentrations in the Po River Basin From 2013–2021



The PRB experienced an average relative poverty incidence of 5.6% (of households) from 2014–2022. The poverty incidence ranged from 3.2% to 11.7% with an average minimum incidence of 4.3% and an average maximum incidence of 7.6%. Poverty incidence peaked in 2016 with an average incidence of 6.4%.

The CRB experienced an average poverty rate of 14.42% (of individuals) from 2013–2022. The poverty rate ranged from 3.6% to 38.7% with an average minimum rate of 10.7% and an average maximum rate of 19.4%. Poverty rates peaked in 2014 with an average rate of 15.9%.

Discussion

Prioritizing the salient health-related consequences of drought is a critical step for public health practitioners and policymakers, because identifying the most salient consequences allows for a targeted, actionable, and feasible mitigation strategy (Bardach, 2000). We identified the most salient consequence based on the following criteria: number of people at risk, number of people affected, severity of the hazard, trend (increasing or decreasing) during the study period, and availability of mitigation systems or policies.

Based on the above considerations, the most salient health-related consequence of drought in the PRB is poor air quality. Despite existing regulations, the PRB's average annual particulate matter concentrations remain well above those recommended by the World Health Organization (WHO, 2025). Although particulate matter concentrations declined slightly over the study period, these reductions are insufficient to protect the health of PRB residents. Furthermore, air quality exposes all PRB residents to a variety of severe health hazards. Because poor air

FIGURE 5

Average A) PM_{10} and B) $PM_{2.5}$ Concentrations in the Colorado River Basin (CRB) From 2013–2022

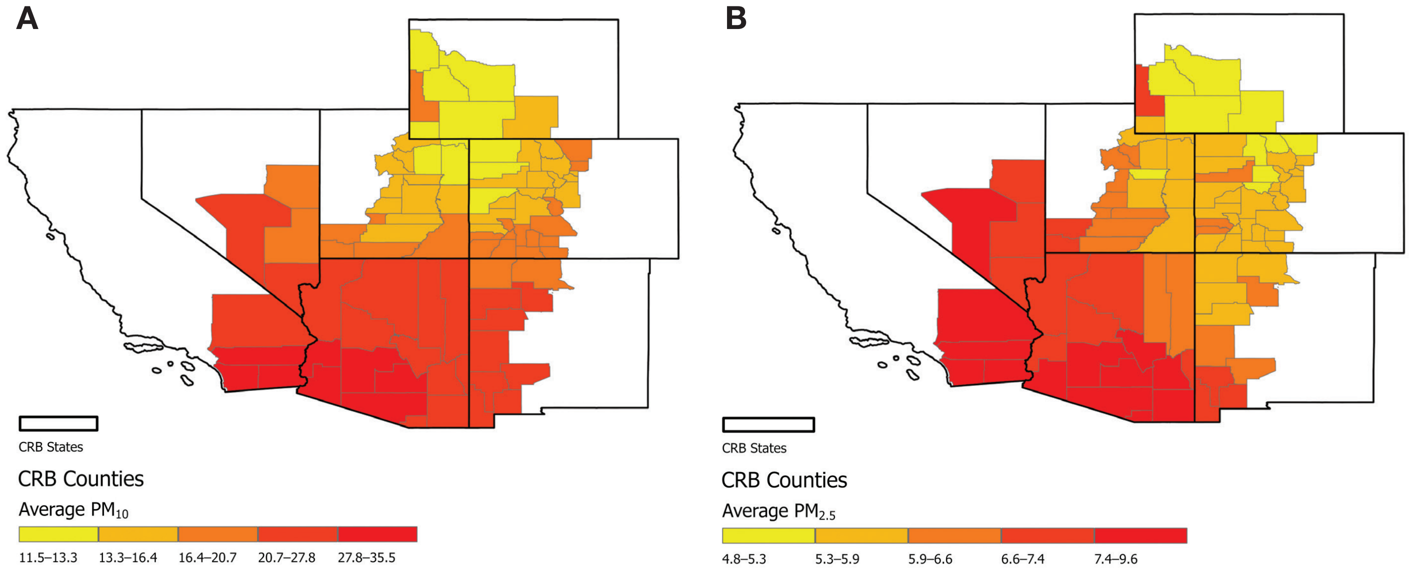
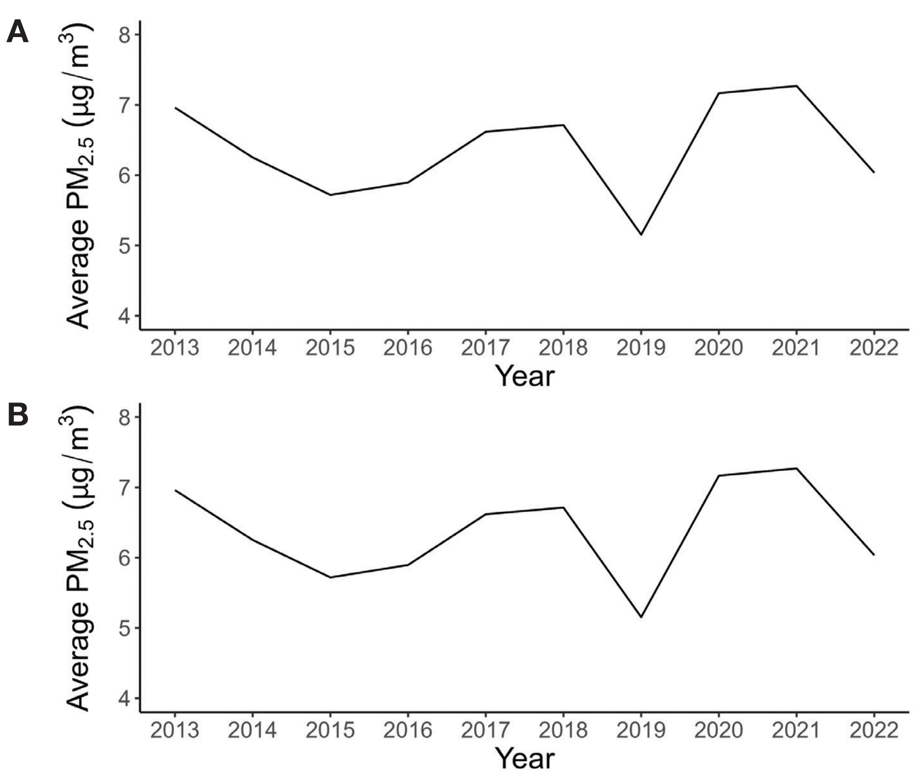


FIGURE 6

Annual Average A) $PM_{2.5}$ and B) PM_{10} Concentrations in the Colorado River Basin From 2013–2022



quality affects all PRB residents and pollutant concentrations remain elevated despite mitigation efforts, public health practitioners and policymakers in Italy should prioritize further interventions to improve air quality in the PRB.

Even though the European Union and Italy regulate the emission of common air pollutants, further collaboration between industry regulators and public health practitioners is indicated. During the study period, the annual average $PM_{2.5}$ concentration remained below the threshold regulated by the European Union; however, some monitors reported a daily average concentration much higher than that recommended by WHO (*Directive 2008/50/EC of the European Parliament*, 2008).

Therefore, Italian public health practitioners must have systems in place to educate residents and mitigate potential health effects during times of high particulate matter concentrations. The Italian government should implement an air quality warning system (such as those used to communicate severe weather) to alert PRB residents to the health risks posed by periods of poor air quality. In addition to triggering messaging, the alert system should indicate masking recommendations. Public health practitioners could then reduce the burden of poor air quality days by pairing masking recommendations with increased availability of free, quality masks or respirators (e.g., via free mask vending machines).

The most salient health-related consequence of drought in the CRB is coccidioidomycosis. Valley fever poses a health risk to all CRB residents, and those who are infected can experience severe, chronic symptoms. Alarmingly, Valley fever cases in the CRB doubled over the study period (Figure 8), and no large-scale mitigation efforts exist. Furthermore, the geographic spread of coccidioidomycosis could further increase the burden of Valley fever in the CRB. Thus, public health practitioners and policymakers should enact solutions to curtail the transmission and spread of Valley fever.

Control of coccidioidomycosis transmission, however, presents a unique challenge for policymakers and is hindered by the absence of a consistent, unified reporting system in the CRB. While there are national mandates for reporting Valley fever, not every state is required to report it, and some health departments do not notify the CDC of Valley fever cases. Thus, Valley fever data are available for most of the CRB; however, no data are available for Colorado and granular data (i.e., county-level) are available only for Arizona and California.

In this way, Valley fever is not unlike other emerging or zoonotic public health challenges such as toxoplasmosis. This lack of consistent reporting creates knowledge gaps in Valley fever transmission and geographic distribution. To improve understanding of Valley fever distribution and transmission in the CRB, the states of Colorado, Nevada, New Mexico, Utah, and Wyoming should report county-level Valley fever data to CDC.

Even with a unified, consistent reporting system, many coccidioidomycosis cases, especially asymptomatic ones, will remain unreported; however, a joint, One Health reporting system could facilitate robust surveillance. Dogs are more susceptible to coccidioidomycosis than humans and, therefore, can serve as sentinels for human disease. Thus, an integrated human–animal reporting system will more accurately detect Valley fever transmission. Creating an integrated,

FIGURE **7**

Average Valley Fever Incidence per 100,000 Residents in the Colorado River Basin From 2013–2022

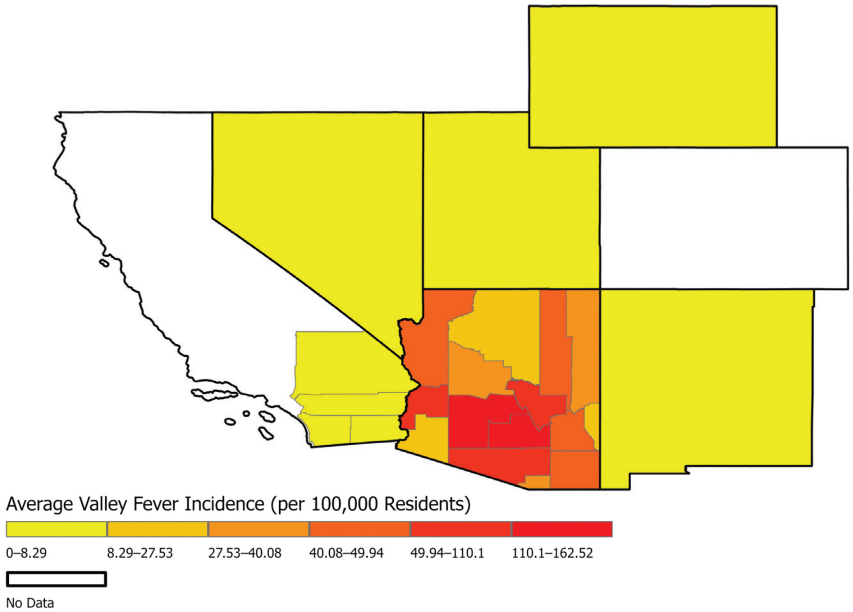


FIGURE **8**

Total Valley Fever Cases and Median Valley Fever Incidence in the Colorado River Basin From 2013–2022

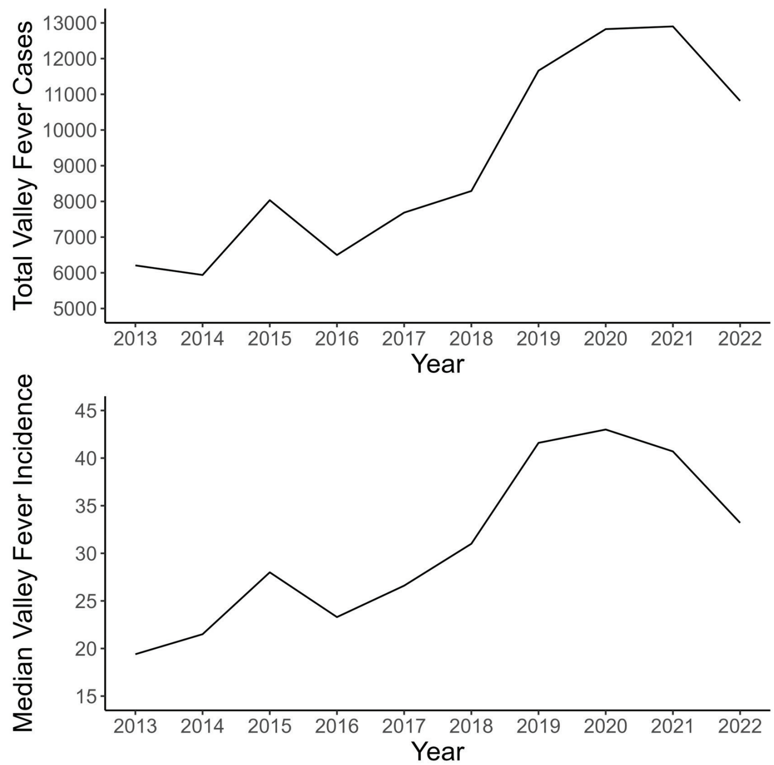


FIGURE **9**

Average Nitrate Concentrations in the Po River Basin From 2013–2021

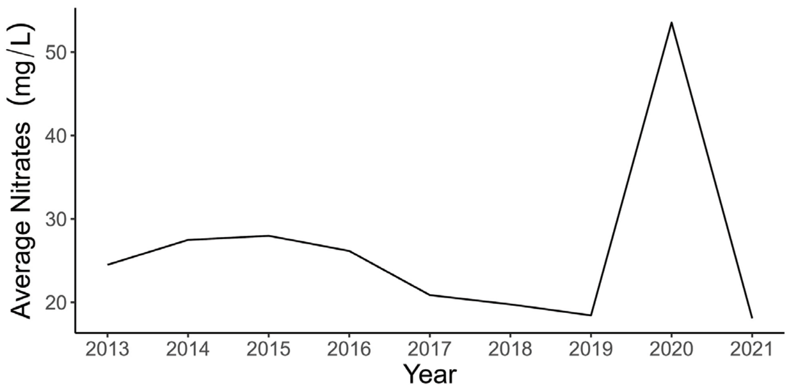
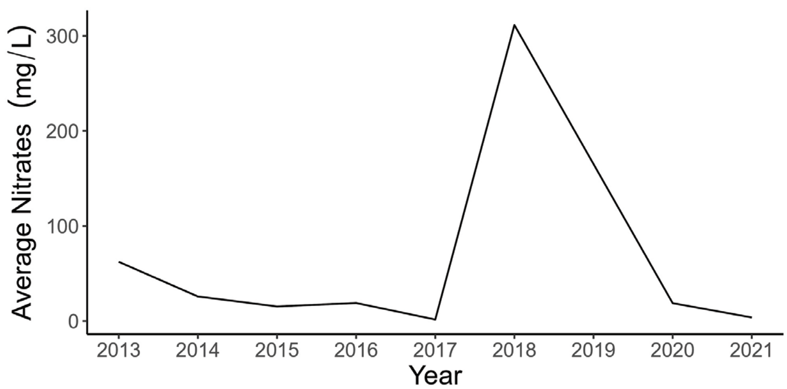


FIGURE **10**

Average Nitrate Concentrations in the Colorado River Basin From 2013–2021



One Health reporting system will allow public health practitioners and policymakers to better understand coccidioidomycosis transmission and then design interventions.

Conclusion

Based on publicly available data about drought-related public health concerns of air quality, water safety, WNV, and relative poverty, public health practitioners and policymakers in Northern Italy must further mitigate particulate matter pollution in the PRB. Similarly, public health practitioners and policymakers in the Western U.S. must mitigate the transmission and geographic spread of coccidioidomycosis in the CRB.

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References

Arizona Department of Health Services. (2025). *Valley fever.* http://www.azdhs.gov/preparedness/epidemiology-disease-control/valley-fever/index.php

Baltaci, H., Akkoyunlu, B.O., Arslan, H., Yetemen, O., & Ozdemir, E.T. (2019). The influence of meteorological conditions and atmospheric circulation types on PM_{10} levels in western Turkey. *Environmental Monitoring and Assessment*, *191*(7), Article 466. https://doi.org/10.1007/s10661-019-7609-7

Bardach, E. (2000). *A practical guide for policy analysis: The eightfold path to more effective problem solving* (1st ed.). CQ Press.

Benoit, J.B., & Denlinger, D.L. (2007). Suppression of water loss during adult diapause in the northern house mosquito, *Culex pipiens*. *Journal of Experimental Biology*, *210*(2), 217–226. https://doi.org/10.1242/jeb.02630

Bhugra, D. (2004). Migration and mental health. *Acta Psychiatrica Scandinavica*, *109*(4), 243–258. https://doi.org/10.1046/j.0001-690X.2003.00246.x

Bi, W., Weng, B., Yuan, Z., Yang, Y., Xu, T., Yan, D., & Ma, J. (2019). Evolution of drought–flood abrupt alternation and its impacts on surface water quality from 2020 to 2050 in the Luanhe River Basin. *International Journal of Environmental Research and Public Health*, *16*(5), Article 691. https://doi.org/10.3390/ijerph16050691

Bo, M., Mercalli, L., Pognant, F., Cat Berro, D., & Clerico, M. (2020). Urban air pollution, climate change and wildfires: The case study of an extended forest fire episode in Northern Italy favoured by drought and warm weather conditions. *Energy Reports*, *6*(Suppl. 1), 781–786. https://doi.org/10.1016/j.egyr.2019.11.002

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References *continued from page 15*

Borgomeo, E., Damania, R., Jägerskog, L.A., Khan, A.M., Russ, J.D., & Zaveri, E.D. (2021). *Ebb and flow, volume 1: Water, migration, and development*. World Bank Group Publications. https://documents.worldbank.org/curated/en/681141629794783791

Brewis, A., Workman, C., Wutich, A., Jepson, W., Young, S., & Household Water Insecurity Experiences–Research Coordination Network (HWISE-RCN). (2020). Household water insecurity is strongly associated with food insecurity: Evidence from 27 sites in low- and middle-income countries. *American Journal of Human Biology*, *32*(1), e23309. https://doi.org/10.1002/ajhb.23309

California Department of Public Health. (2024). *Valley fever in California year-end data dashboard*. https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/ValleyFeverDashboard.aspx

Centers for Disease Control and Prevention. (n.d.). *National Notifiable Diseases Surveillance System (NNDSS)*. https://stacks.cdc.gov/cbrowse?pid=cdc%3A49375&parentId=cdc%3A49375

Centers for Disease Control and Prevention. (2025). *West Nile virus: Historic data (1999–2023): West Nile virus*. https://www.cdc.gov/west-nile-virus/data-maps/historic-data.html?CDC_AAref_Val=https://www.cdc.gov/westnile/statsmaps/historic-data.html

Davis, J.K., Vincent, G.P., Hildreth, M.B., Kightlinger, L., Carlson, C., & Wimberly, M.C. (2018). Improving the prediction of arbovirus outbreaks: A comparison of climate-driven models for West Nile virus in an endemic region of the United States. *Acta Tropica*, *185*, 242–250. https://doi.org/10.1016/j.actatropica.2018.04.028

Dean, J.G., & Stain, H.J. (2010). Mental health impact for adolescents living with prolonged drought. *The Australian Journal of Rural Health, 18*(1), 32–37. https://doi.org/10.1111/j.1440-1584.2009.01107.x

Defrance, D., Delesalle, E., & Gubert, F. (2023). Migration response to drought in Mali. An analysis using panel data on Malian localities over the 1987-2009 period. *Environment and Development Economics*, 28(2), 171–190. https://doi.org/10.1017/S1355770X22000183

Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe. (2008). European Parliament, Council of the European Union. http://data.europa.eu/eli/dir/2008/50/oj/eng

European Centre for Disease Prevention and Control. (2024, February 20). *Transmission of West Nile virus, 2023 season*. https://www.ecdc.europa.eu/en/publications-data/transmission-west-nile-virus-2023-season

European Environment Agency. (2024). *[EU SDG 06_40] Nitrate in groundwater* [Data set]. https://www.eea.europa.eu/en/datahub/datahubitem-view/ff63d80d-a1e8-414b-9a42-6b35d54fff30

European Environment Agency. (2025a). *PM_{10}, European air quality data, (interpolated data)* [Data set]. https://www.eea.europa.eu/en/datahub/datahubitem-view/abc66a42-b595-4e0f-9772-b862dc454e9f

European Environment Agency. (2025b). *$PM_{2.5}$, European air quality data, (interpolated data)* [Data set]. https://www.eea.europa.eu/en/datahub/datahubitem-view/938bea70-07fc-47e9-8559-8a09f7f92494

Feng, S., Gao, D., Liao, F., Zhou, F., & Wang, X. (2016). The health effects of ambient $PM_{2.5}$ and potential mechanisms. *Ecotoxicology and Environmental Safety*, *128*, 67–74. https://doi.org/10.1016/j.ecoenv.2016.01.030

Friel, S., Berry, H., Dinh, H., O'Brien, L., & Walls, H.L. (2014). The impact of drought on the association between food security and mental health in a nationally representative Australian sample. *BMC Public Health*, *14*(1), Article 1102. https://doi.org/10.1186/1471-2458-14-1102

Gosling, S.N., & Arnell, N.W. (2016). A global assessment of the impact of climate change on water scarcity. *Climatic Change*, *134*(3), 371–385. https://doi.org/10.1007/s10584-013-0853-x

Gray, C., & Mueller, V. (2012). Drought and population mobility in rural Ethiopia. *World Development*, *40*(1), 134–145. https://doi.org/10.1016/j.worlddev.2011.05.023

Gushulak, B.D., & MacPherson, D.W. (2007). Migration in a mobile world: Health, population mobility, and emerging disease. In Y. Apostolopoulos, & S. Sönmez (Eds.), *Population mobility and infectious disease* (pp. 283–300). Springer. https://doi.org/10.1007/978-0-387-49711-2_15

Hagan, R.W., Didion, E.M., Rosselot, A.E., Holmes, C.J., Siler, S.C., Rosendale, A.J., Hendershot, J.M., Elliot, K.S.B., Jennings, E.C., Nine, G.A., Perez, P.L., Rizlallah, A.E., Watanabe, M., Romick-Rosendale, L.E., Xiao, Y., Rasgon, J.L., & Benoit, J.B. (2018). Dehydration prompts increased activity and blood feeding by mosquitoes. *Scientific Reports*, *8*(1), Article 6804. https://doi.org/10.1038/s41598-018-24893-z

Hagos, S., Lunde, T., Mariam, D.H., Woldehanna, T., & Lindtjørn, B. (2014). Climate change, crop production and child under nutrition in Ethiopia; A longitudinal panel study. *BMC Public Health*, *14*(1), Article 884. https://doi.org/10.1186/1471-2458-14-884

Hanigan, I.C., & Chaston, T.B. (2022). Climate change, drought and rural suicide in New South Wales, Australia: Future impact scenario projections to 2099. *International Journal of Environmental Research and Public Health*, *19*(13), Article 7855. https://doi.org/10.3390/ijerph19137855

Head, J.R., Sondermeyer-Cooksey, G., Heaney, A.K., Yu, A.T., Jones, I., Bhattachan, A., Campo, S.K., Wagner, R., Mgbara, W., Phillips, S., Keeney, N., Taylor, J., Eisen, E., Lettenmaier, D.P., Hubbard, A., Okin, G.S., Vugia, D.J., Jain, S., & Remais, J.V. (2022). Effects of precipitation, heat, and drought on incidence and expansion of coccidioidomycosis in western USA: A longitudinal surveillance study. *The Lancet Planetary Health*, *6*(10), e793–e803. https://doi.org/10.1016/S2542-5196(22)00202-9

Hu, Y., Wang, S., Yang, X., Kang, Y., Ning, G., & Du, H. (2019). Impact of winter droughts on air pollution over Southwest China. *Science of the Total Environment*, *664*, 724–736. https://doi.org/10.1016/j.scitotenv.2019.01.335

References

Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: AR6 synthesis report*. https://www.doi.org/10.59327/IPCC/AR6-9789291691647

Italian National Institute of Statistics (Istat). (2023). *Poor households—Region residence* [Data set]. https://esploradati.istat.it/databrowser/#/en/dw/categories/IT1,HOU,1.0/HOU_POVER/DCCV_POVERTA/IT1,34_727_DF_DCCV_POVERTA_8,1.0

Jankowska, M.M., Lopez-Carr, D., Funk, C., Husak, G.J., & Chafe, Z.A. (2012). Climate change and human health: Spatial modeling of water availability, malnutrition, and livelihoods in Mali, Africa. *Applied Geography*, *33*, 4–15. https://doi.org/10.1016/j.apgeog.2011.08.009

Johnson, B.J., & Sukhdeo, M.V.K. (2013). Drought-induced amplification of local and regional West Nile virus infection rates in New Jersey. *Journal of Medical Entomology*, *50*(1), 195–204. https://doi.org/10.1603/ME12035

Jülich, S. (2011). Drought triggered temporary migration in an east Indian village. *International Migration*, *49*(Suppl. 1), e189–e199. https://doi.org/10.1111/j.1468-2435.2010.00655.x

Kilpatrick, A.M., Meola, M.A., Moudy, R.M., & Kramer, L.D. (2008). Temperature, viral genetics, and the transmission of West Nile virus by *Culex pipiens* mosquitoes. *PLOS Pathogens*, *4*(6), e1000092. https://doi.org/10.1371/journal.ppat.1000092

Landes, D.S. (1999). *The wealth and poverty of nations: Why some are so rich and some so poor*. W.W. Norton & Company.

Levy, Z.F., Jurgens, B.C., Burow, K.R., Voss, S.A., Faulkner, K.E., Arroyo-Lopez, J.A., & Fram, M.S. (2021). Critical aquifer overdraft accelerates degradation of groundwater quality in California's Central Valley during drought. *Geophysical Research Letters*, *48*(17), Article e2021GL094398. https://doi.org/10.1029/2021GL094398

Li, Y., Sun, J., Lei, R., Zheng, J., Tian, X., Xue, B., & Luo, B. (2023). The interactive effects between drought and air pollutants on children's upper respiratory tract infection: A time-series analysis in Gansu, China. *International Journal of Environmental Research and Public Health*, *20*(3), Article 1959. https://doi.org/10.3390/ijerph20031959

Lieber, M., Chin-Hong, P., Kelly, K., Dandu, M., & Weiser, S.D. (2020). A systematic review and meta-analysis assessing the impact of droughts, flooding, and climate variability on malnutrition. *Global Public Health*, *17*(1), 68–82. https://doi.org/10.1080/17441692.2020.1860247

Lippmann, M. (2020). Ambient air particulate matter. In M. Lippmann & G.D. Leikauf (Eds.), *Environmental toxicants: Human exposures and their health effects* (4th ed., pp. 285–365). John Wiley & Sons.

Maxwell, N.I. (2013). *Understanding environmental health: How we live in the world* (2nd ed.). Jones & Bartlett Learning.

National Water Quality Monitoring Council, U.S. Geological Survey, & U.S. Environmental Protection Agency. (2021). *Water quality portal* [Data set]. https://doi.org/10.5066/P9QRKUVJ

Nguyen, C., Barker, B.M., Hoover, S., Nix, D.E., Ampel, N.M., Frelinger, J.A., Orbach, M.J., & Galgiani, J.N. (2013). Recent advances in our understanding of the environmental, epidemiological, immunological, and clinical dimensions of coccidioido mycosis. *Clinical Microbiology Reviews*, *26*(3), 505–525. https://doi.org/10.1128/cmr.00005-13

Oki, T., & Kanae, S. (2006). Global hydrological cycles and world water resources. *Science*, *313*(5790), 1068–1072. https://www.doi.org/10.1126/science.1128845

Paull, S.H., Horton, D.E., Ashfaq, M., Rastogi, D., Kramer, L.D., Diffenbaugh, N.S., & Kilpatrick, A.M. (2017). Drought and immunity determine the intensity of West Nile virus epidemics and climate change impacts. *Proceedings of the Royal Society: Biological Sciences*, *284*(1848), 1–10. https://www.doi.org/10.1098/rspb.2016.2078

Reisen, W.K., Fang, Y., & Martinez, V.M. (2006). Effects of temperature on the transmission of West Nile virus by *Culex tarsalis* (Diptera: Culicidae). *Journal of Medical Entomology*, *43*(2), 309–317. https://doi.org/10.1093/jmedent/43.2.309

Ruiz, M.O., Chaves, L.F., Hamer, G.L., Sun, T., Brown, W.M., Walker, E.D., Haramis, L., Goldberg, T.L., & Kitron, U.D. (2010). Local impact of temperature and precipitation on West Nile virus infection in *Culex* species mosquitoes in northeast Illinois, USA. *Parasites & Vectors*, *3*(1), Article 19. https://doi.org/10.1186/1756-3305-3-19

Sartore, G.-M., Kelly, B., Stain, H., Albrecht, G., & Higginbotham, N. (2008). Control, uncertainty, and expectations for the future: A qualitative study of the impact of drought on a rural Australian community. *Rural and Remote Health*, *8*(3), Article 950. https://doi.org/10.22605/RRH950

Shriber, J., Conlon, K.C., Benedict, K., McCotter, O.Z., & Bell, J.E. (2017). Assessment of vulnerability to coccidioidomycosis in Arizona and California. *International Journal of Environmental Research and Public Health*, *14*(7), Article 680. https://doi.org/10.3390/ijerph14070680

Šmejkalová, A.H., & Brzezina, J. (2022). The effect of drought on PM concentrations in the Czech Republic. *Aerosol and Air Quality Research*, *22*(10), Article 220130. https://doi.org/10.4209/aaqr.220130

Tobin, K.J., Pokharel, S., & Bennett, M.E. (2022). Coccidioidomycosis (Valley fever), soil moisture, and El Niño Southern Oscillation in California and Arizona. *International Journal of Environmental Research and Public Health*, *19*(12), Article 7262. https://doi.org/10.3390/ijerph19127262

U.S. Census Bureau. (2023). *SAIPE datasets*. https://www.census.gov/programs-surveys/saipe/data/datasets.html

U.S. Environmental Protection Agency. (2023, October 26). *Air data file download page* [Data & tools]. https://aqs.epa.gov/aqsweb/airdata/download_files.html#Daily

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References *continued from page 17*

Vins, H., Bell, J., Saha, S., & Hess, J.J. (2015). The mental health outcomes of drought: A systematic review and causal process diagram. *International Journal of Environmental Research and Public Health*, *12*(10), 13251–13275. https://doi.org/10.3390/ijerph121013251

Wang, Y., Xie, Y., Dong, W., Ming, Y., Wang, J., & Shen, L. (2017). Adverse effects of increasing drought on air quality via natural processes. *Atmospheric Chemistry and Physics*, *17*(20), 12827–12843. https://doi.org/10.5194/acp-17-12827-2017

Weaver, E.A., & Kolivras, K.N. (2018). Investigating the relationship between climate and Valley fever (coccidioidomycosis). *EcoHealth*, *15*(4), 840–852. https://doi.org/10.1007/s10393-018-1375-9

Wickham, H. (2009). *ggplot2: Elegant graphics for data analysis* (1st ed.). Springer. https://doi.org/10.1007/978-0-387-98141-3

World Health Organization. (2025). *What are the WHO air quality guidelines?* https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines

Yeboah, E., Kuunibe, N., Mank, I., Parisi, D., Bonnet, E., Lohmann, J., Hamadou, S., Picbougoum, B.T., Belesova, K., Sauerborn, R., Baernighausen, T., Danquah, I., & Allegri, M.D. (2022). Every drop matters: Combining population-based and satellite data to investigate the link between lifetime rainfall exposure and chronic undernutrition in children under five years in rural Burkina Faso. *Environmental Research Letters*, *17*(5), Article 054027. https://doi.org/10.1088/1748-9326/ac661c

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