# Flooding:

**WATER-RELATED DISEASE**

Decreased water availability is a defining feature of most droughts. Related to this, water quality can also be affected [64](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref64). The relationship between water quantity and quality is complex [65](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref65). An important point, not always fully appreciated, is that both are necessary for good health [66](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref66). Seasonal variations in water related health outcomes are well-recognised [67](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref67) but whether drought should be considered as a prolonged dry season or a separate phenomenon altogether is a matter for debate.

As water discharge and water levels associated with droughts are typically low, dilution capacity is reduced and secondary impacts on freshwater systems emerge such as poorer water quality (e.g., higher concentration in chemical, nutrients and solid particles, lower dissolved oxygen) [68](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref68). Water quality can further worsen when intense rainfall follows a long dry spell (typically from convective storms associated with high summer temperature) and chemicals accumulated on the ground or roads wash out to the rivers [69](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref69). When dry spells are associated with anticyclonic conditions and high temperatures, this can speed up the development of droughts and increase the risk of secondary impacts. In particular, high temperatures result in high evaporative losses, drying up soil and plants; this can trigger agricultural droughts and increase wildfire risk. With dryer soils, infiltration capacity can also reduce and flooding risk can increase.

Also relevant to resource-rich countries as well as resource-poor is that people may switch their water source during drought, often to a lower quality supply. For instance, recent droughts in the UK have tempted people to consider private water supplies which are not under such direct control of water company drought restrictions [70](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref70). A risk of this is potentially poorer quality control: several outbreaks of infectious disease associated with private water supplies in England and Wales have been described [71](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref71). Recycling water is another option which people may resort to during drought: this too has risks for human health [72](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref72). Table 3 summarises studies which were explicit about drought linked to water-related disease. There were several categories of effect:

**Water-related disease caused by faecal/urine pollution**

Paucity of water sources during drought may increase the risk of remaining sources being contaminated by faces or urine: for instance, if an increased number of animals are drawn to drink by a river or borehole [73](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref73). Infected humans can also contribute to transmission around a water source: the more users there are, the more are at-risk and the more likely an outbreak of infectious disease. Associated risks might be further exacerbated if the water source in question is running at low levels; pathogens are more concentrated than normal [74](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref74) and it is more likely that anybody consuming the water would ingest a minimum infective dose.

Diseases which are transmitted by water and hence potentially affected by drought include amoebiasis, hepatitis A, salmonellosis, schistosomiasis, shigellosis, typhoid and paratyphoid (enteric fever). Evidence is, however, scarce. Few papers directly addressed this topic and were limited to drought-associated E.coli O157 [75](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref75); cholera [76](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref76) , [77](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref77), and leptospirosis [78](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref78). In all these studies, it is important to note that drought was not the only exposure underlying the outbreak-- a whole chain of risk factors was responsible. Reflecting this upstream role, drought-related potential disease risk does not always translate to actual disease. In Haiti in 1976-1977, area-level comparison of severely and moderately drought affected areas showed no differences in reported diarrhoeal disease [79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref79). Factors which did show an effect were: unemployed head of household; household socioeconomic status; large family size; quantity of water used (<19 litres/person/day).

**Skin, eye and louse-borne disease that occur when there is lack of water for personal hygiene**

Skin infections associated with lack of water for washing include scabies [79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref79), and impetigo – though we found no clear drought-associated references for the latter. Eye infections including conjunctivitis [79](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref79) were also associated with drought-related lack of water for washing.

# Drought:

**AIRBORNE AND DUST-RELATED DISEASE**

As soils become increasingly dry during a drought, dust circulated in the air is more likely. The United States dust bowl drought of the 1930s is a particularly well known example of this: hundreds and perhaps thousands of people who lived in the Great Plains died from “dust pneumonia,” a respiratory condition brought on by inhalation of excessive amounts of dust and dirt [86](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref86). Dust can be harmful via two mechanisms: pathogen carriage and direct trauma from inhaled particulates. In South Korea, one examination of dust clouds blown in by winds from the Mongolian desert found weak evidence of an association with mortality: a 1.7% (95% CI -1.6 to 5.3) increase in all cause deaths; a 2.2% (95% CI -3.5 to 8.3) increase in deaths among those aged 65 years and older; a 4.1% (95% CI -3.8 to 12.6) increase in deaths from cardiovascular and respiratory causes [87](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref87). A 2012 review of health impacts of desert dust found 50 studies describing a range of health effects including respiratory, cardiovascular and cardiopulmonary disease [88](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref88).

Table 4 summarizes reports linking drought to airborne/dust-related disease. Few studies were found making this link. Possible reasons for this lack of evidence include: 1) because the bulk of morbidity is in permanently dry (arid) areas, and our search did not include permanently arid conditions; 2) because the drought-dust link is often only implicit, not well enough described to be flagged by our search terms; 3) because the difference between an arid area and one affected by long term drought is a matter of degree and hence subjective. It is biologically plausible to assume that the health effects of drought-related dusts will be similar to those of dust in general [88](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref88) – possibly less severe for conditions where duration of exposure is relevant (assuming a drought is a time-limited event). As with previous sections, many of the respiratory effects of drought were indirect.

In a 1987-1989 Canadian drought, dust from a dried lake was associated with significant self-reported respiratory problems including cough and wheeze. Lung function did not, however, seem to be affected. Anxiety may have been responsible for symptom self-reporting, and short term exposure to dust may have been insufficient to cause measurable lung damage [89](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref89).

Another example of drought-related problems due to inhalation (this time of gas rather than dust) comes from case reports from New York. These described silo-gas exposure associated with the fact that a dry growing season raises nitrate levels in corn plants. As plants in silos biodegrade, they release nitrogen dioxide (NO2). Farm workers maintaining the silos were exposed to unusually high levels of NO2 resulting in hospitalization some cases: though important to note that this could have been fatal had levels been higher or exposure longer [90](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref90).

Coccidioidomycosis (Valley Fever) shows the complex relationship with drought and other environmental events. It is caused by a fungus, Coccidioides, which lives in the soil of dry, low rainfall areas and is acquired by breathing in spores from the air. It can, for instance, be distributed during dust storms [91](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref91). Outbreaks in California were associated with heavy rains following a drought, possibly exacerbated by building work which disturbed the soil and released more spores than might otherwise have been the case [92](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref92). Another study on coccidioidomycosis was one of the few in this review which correlated drought intensity with increased incidence of disease, with a significant association (p<0.01) [93](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref93).

**VECTOR-BORNE DISEASE**

Our search revealed a number of papers which examined the impact of drought on various vector-borne diseases; eight met the inclusion criteria and are summarised in Table 5, and several others are used as supporting evidence in this section. The relationship between vector-borne diseases and climatological conditions is an important area to consider when planning public health drought mitigation strategies, and more research on each disease is needed to strengthen the existing evidence which, in many cases, is not definitive and quite sparse.

The mosquito is one of the most important arthropod vectors involved in the transmission of various vector-borne pathogens, and increased precipitation can cause mosquito densities to increase through provision of additional aquatic habitat. In a study of US wetlands that never dry compared to wetlands that dry annually, it was found that mosquito densities increase dramatically following natural drought events [94](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref94), and this was explained in the main through loss of competitors and predators thus allowing a rapid increase in mosquito numbers following re-colonisation resulting from re-wetting post-drought.

**Dengue**

An outbreak of dengue in1994 in Brazil was linked to a shortage of public water supplies as the result of a prolonged drought; increased mosquito abundance correlated with widespread household storage of water and with interrupted dengue suppression activities [95](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref95).

Given the prospect of climate change forecasts projecting increased drying conditions and decreased rainfall in Australia, projections of Aedes aegypti mosquito distribution were studied under current climate conditions and climate change scenarios for 2030 and 2050. Results indicate that the proliferation of domestic water storage tanks, used as an adaptation strategy during drought conditions, may expand the range of Ae. aegypti and create a high potential for dengue transmission during warm summer months [96](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref96). This phenomenon is likely to impact all urban mosquitoes that have adapted to exploit container habitats.

**Malaria**

Evidence of malaria associated with drought is mixed, and research on the effects of El Niño Southern Oscillation (ENSO) should be consulted to understand the global trends of drought patterns and their relationship to health.

One study which examined the link between malaria and ENSO found that malaria mortality is strongly related to drought in the year before outbreaks in Venezuela [97](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref97). Another study which examined ENSO and malaria epidemics in South America found that droughts are associated with malaria epidemics in Colombia (in the first year of an El Niño episode or in the year following the onset), Guyana (in the first year of an El Niño episode or in the year following the onset) and Venezuela (epidemics follow drought by one year) [98](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref98).

It is important to consider that some anopheline species exploit container habitats (water storage, or rainwater collecting habitats), while others require permanent water. The former applies to Anopheles arabiensis, and the latter applies to Anopheles funestus; both principle malaria vectors in Africa. The aquatic habitat favoured by the local malaria vectors is therefore crucial in determining the impact of drought on malaria.

In the Sahel, one study looked at Anopheles funestus and changes over time in malaria prevalence and incidence. In Senegal, between 1967 and 1992, parasite prevalence in children fell by 84%, and incidence fell by 82%. In Niger, malaria prevalence fell from 69% in 1969 to 23% in 1994 in the Niger River area; in Zinder, prevalence dropped from 89% in 1922 to 32% in 1994, and near Lake Chad, prevalence dropped from 40% in 1967 to 7% in 1996. The authors report that the decreases in malaria prevalence and incidence are likely due to the disappearance of the A. funestus as a result of severe droughts in the region [99](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref99). Another study of Plasmodium falciparum transmission by Anopheles arabiensis and Anopheles funestus during a period of drought (2004-2005) in Zambia reported reduced mosquito activity and reduced numbers of malaria cases during the period of drought. Numbers of An. arabiensis rebounded strongly when the rains returned in 2005-2006, while no An. funestus were collected during this time [100](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref100). The former is able to exploit the multitude of transient aquatic habitats following rain events with numbers increasing rapidly in the absence of predators and competitors.

Finally, highlighting the indirect nature of many of the health effects associated with drought, during a period of drought (1997) in the Irian Jaya province of Indonesia, two factors are believed responsible for a sharp rise in malaria cases (554 deaths in three months) amongst highland populations not normally exposed to malaria: severe food and water shortages in the highlands contributed to population migration to lower elevations where intense malaria transmission is common, and drought conditions resulted in numerous pools of standing water (normally fast-flowing), permitting a rapid increase in vector populations. The findings show a temporal association with ENSO-related drought and increases in malaria and associated deaths [101](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref101).

**St Louis encephalitis virus**

Evidence suggests that antecedent drought followed by wet conditions facilitated the amplification of the St Louis encephalitis (SLE) virus among Culex nigripalpus mosquitoes and a portion of wild birds in Florida, USA, resulting in subsequent transmission to humans [102](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref102) , [103](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref103). In another study water table depth was compared with human cases of SLE in Florida and results showed that May drought occurred in 83% of the areas studied prior to the report of at least one human case of SLE [104](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref104). This study builds on the previous studies and provides further evidence that antecedent drought and near-coincident wetting are significantly associated with human SLE cases. Culex mosquitoes tend to exploit transient water bodies and can proliferate in the absence of predators.

**West Nile Virus**

A number of studies have identified links between human West Nile virus (WNV) and drought in the United States. In a study comparing transmission patterns of WNV in California from 2004-2007, increases in human infection in 2007 were associated with severe drought conditions as well as other surveillance indicators including neglected swimming pools [105](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref105). In a study of human WNV incidences compared with annual rainfall levels in Mississippi, an inverse relationship was identified between precipitation levels of the previous year and the relative risk of human WNV, suggesting that drought acts as a potential mechanism for increased risk of human WNV transmission; given climate change projections for increased drought in certain areas of the world, the authors believe that the risk of human WNV will also increase [106](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref106). In western Colorado, dry spring and summer conditions appear to increase the risk of human WNV infection [107](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref107). In the eastern US, another study found that WNV proliferates under drought conditions [108](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref108). Similar to findings about SLE, one study found that widespread drought conditions in the spring, followed by a wetter summer, increase the probability of human WNV cases [109](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref109).

**Rift Valley fever virus**

Transmission of Rift Valley fever virus (RVFV) is reported to be epizootic during wet years, especially following droughts; uncontrolled air travel could introduce RVFV to North America or Europe where susceptible hosts and suitable vectors reside, and could potentially have serious impacts on human health [110](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref110). The virus survives in the eggs of Aedes mosquitoes. These mosquitoes survive out of water in areas prone to flooding, such as dambos or depressions, which are their main aquatic habitats in West Africa. Following heavy rainfall events, these habitats flood, and the resulting infected adults (from infected eggs) emerge to transmit the virus to animals. The pathogen is then passed from animals onto the local Culex populations precipitating a much larger outbreak. Flooding following drought results in large-scale simultaneous hatching of infected eggs and thus simultaneous outbreaks of RVFV across Africa.

**Japanese encephalitis**

One study which examined an epidemic of Japanese encephalitis in Andhra Pradesh, India, noted that drought conditions existed before the epidemic started in the sample population; however, this was not explored thoroughly as a potential risk factor which contributed to the outbreak [111](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref111).

**Chikungunya**

One study which used satellite data and epidemiologic investigation to examine epidemics of chikungunya in Kenya found that unusually warm and dry conditions preceded outbreaks of chikungunya (63% of population tested), suggesting that drought-affected populations may be at a higher risk for chikungunya infection [112](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref112). The study’s small sample size and lack of other studies to compare make it difficult to generalize findings. Throughout its range chikungunya is transmitted by Aedes mosquitoes that exploit container habitats in urban areas, so water storage during drought is likely to favour these vectors and transmission of this virus.

**Tick-borne disease**

A study measuring both the prevalence and incidence of tick-borne borreliosis in Senegal reports an average annual incidence rate of 5.1% in the sample population and 0.09% prevalence in a different sample population. The authors attribute the persistence of sub-Saharan drought as a possible source responsible for the spread of the Alectorobius sonrai vector to new areas of West Africa [113](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref113) , [114](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref114); further investigation is necessary to confirm these findings.

Another study of tick-borne relapsing fever from the same site in Senegal, this one a 14 year longitudinal study, found an average incidence rate of 11 per 100 person-years; the authors also attributed the ongoing sub-Saharan drought as a factor responsible for the spread of the

Ornithodoros sonrai vector to the West African savannah [115](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref115). Again, more research is necessary to understand the possible relationship between drought and this disease. As the majority of tick species in more temperate parts of the world are reliant upon retaining their body moisture content, drought conditions would not tend to favour such ‘forest-species’. However, in arid areas, the effect of drought is likely to be much less.

**Schistosomiasis**

One study which compared the prevalence of Schistosoma haematobium in coastal Kenya in 2000 and 2009 recorded the disappearance of schistosomiasis infection clusters and a slight decline in prevalence from 55.7% to 43.2% following periods of prolonged drought [116](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref116). Schistosoma parasites require an aquatic snail as a vector, hence drought probably reduces the number of these snails and reduces the transmission potential. Furthermore, humans become infected when standing in water with infective metacercariae, therefore less available water during a drought will mean a lower exposure to the pathogens.

**Chagas disease**

One study examining an unusually high incidence of Chagas disease in Brazil reported that drought conditions may contribute to outbreaks in humans, yet no information was provided to give evidence of the link between the two [117](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/#ref117).

Refs:

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