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Probable effects of

CLIMATE CHANGE

ON INFECTIOUS DISEASES IN NORTH AMERICA

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ABSTRACT

Over the past decades, public and official concern about infectious diseases as a major public health threat have been renewed. The type of disease – classical, emerging or re-emerging – like tuberculosis, cholera, typhoid fever or dengue, the country in question – developed or developing, and its location – semi-desert, sylvatic or mountain region – defines the kind of concern. However, it is important to consider climate change, and its current and further effects, with the consequent variations in different zones. Distinct regions will be affected in different ways depending on their people, health systems, population size, infrastructure, type of construction material (wood, concrete, or makeshift materials), whether settlements are located close to rivers, hills or valleys, and certainly the local weather. In this paper, we analyze the effects of climate change on the prevalence of the most common waterborne diseases (i.e. typhoid fever, cholera, amoebiasis, cryptosporidiosis, hepatitis A).



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◆ INTRODUCTION

● CLIMATE CHANGE

Several simulation models on climate change indicate that temperatures will increase, resulting in ice melting at the earth poles (CDIAC, 2014, ESS-DIVE, 2018). If this prediction proves true, one of its most likely consequences will be flooding in places close to shores and reduction of free land. This melting will be the consequence of different conditions. One of them, is the reduction of the ozone layer by fluorocarbons due to anthropological release – even though its production and usage have been forbidden. Fluorocarbons have a long life span so, according to the EPA (EPAa, 2014) experts. Even if releasing these compounds were to stop right now, the ozone layer will restore in about 50 years (EPAb, 2014). Another factor that increases global temperature is the accelerated production of greenhouse gases like CO₂ by the combustion of fossil fuels (EPAc, 2014). It has been estimated that since 1751 approximately 400 billion metric tons of carbon have been released to the atmosphere derived from the combustion of fossil fuels and cement production. The 2007 global fossil-fuel carbon emission estimate – 8,365 million metric tons of carbon – represents an all-time high and a 1.7% increase from 2006. (Boden, *et al*, 2010; CDIAC, 2014 ESS-DIVE, 2018).

This scenario indicates what could happen if there is a slight temperature increase in our environment, affecting not only affecting ice melting, but also air, water, and soil temperatures increasing as well. The ice melt will increase and, as a consequence, sea levels and flooding in coastal areas will rise too. An increased air temperature will reduce the dissolved oxygen in the sea and at higher altitudes, reducing oxygen concentration. Oxygen reduction in turn will affect aerobic organisms (aquatic and terrestrial macro and microorganisms). However, the temperature increase will permit the growth of organisms, mainly pathogens or its vectors, in places considered cold. In other words, it will change cold climate to tropical.

● CLIMATE AND HOST-PARASITE RELATIONSHIP

The effects of climate change will alter the complex interaction of host and infectious agents (parasites). Climatic variability has a direct influence on human behavior, which has an impact on the transmission pattern of infectious agents. For example, during cold seasons peo-

IN RAINY AND MILD SEASONS AN AVERAGE TEMPERATURE OF

15°C

FAVORS AN INCREASE IN MALARIA TRANSMISSION.

ple stay in closed environments, which explains why respiratory infections increase in this period, the reason being that the respiratory pathogens are transmitted by air, and if one subject is infected the pathogens will be transmitted easily to others. On the other hand, gastroenteritis in the warm months is associated with activities like going to the beach, eating outdoors, and exposure to recreational water (WHO, 2003).

Climate change can also modify the anthropologic migration patterns, which will alter infectious diseases dissemination, affecting also human settlements and the health structure of every country (Meléndez-Herrada, *et al*, 2008; Feng, *et al* 2010).

Climate patterns change important physical components of ecosystems, and that too will affect all living things including microorganisms, insects' vectors, animal reservoirs, and sensitive people, changing the incidence and distribution of infectious diseases.

The geographic and population dynamics of insect vectors also has a strong relationship with temperature patterns, rain, and humidity. A temperature rise can accelerate the metabolic rate of different insects, affecting their egg production and the frequency of biting. Rain has a direct effect on the longevity of vectors because it provides the proper conditions for insect habitats and extends the geographical distribution and seasonal abundance of such vectors (Mellor & Leake, 2000; Ostfeld 2009).

Climate has a direct impact on a pathogen's development, as virus, bacteria or other parasites, which cannot complete their life cycle due to the need for optimal temperature that affect their replication or reproduction. If temperature increases in places regularly considered cold, it could lead to an increase in multiplication by extending its spread and consequently raising infectious diseases too (WHO, 1999, Kuhn, *et al*, 2005).



DURING THE RAINY SEASON, WHERE HUGE STORMS OCCUR, THE WATER VOLUME CAN EXCEED THE SOIL'S DRAINING CAPACITY AND OVERFLOW WASTEWATER TREATMENT SYSTEMS THAT CAN INVADE THE REGULAR WATER SUPPLY FOR CITIES.

EFFECT OF CLIMATE CHANGE ON INFECTIOUS DISEASES

Climate change can modify how infectious diseases are transmitted from animal or humans in three ways:

1

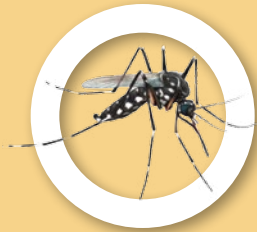
INCREASING
THE RESERVOIR
ANIMAL OR
VECTOR NUMBERS.

2

ENLARGING THE
TRANSMISSION
CYCLES.

3

IMPORTING VECTOR
OR RESERVOIR
ANIMALS TO NEW
REGIONS.



Zoonotic diseases and those transmitted by vectors



Food and waterborne diseases




Respiratory diseases



Fungi invasive diseases




ALL THESE DISEASES CAN FURTHER BE INCREASED AS A RESULT OF CLIMATE CHANGE, BECAUSE MANY OF THE BIGGEST OUTBREAKS OF THESE DISEASES HAVE BEEN RELATED TO EXTREME WATER PRECIPITATION AND FLOODING.

All seasonal variations like temperature, water precipitation, and availability of nutritional resources have a strong influence on a microorganism's population dynamics. For example, in rainy and mild seasons an average temperature of 15°C favors an increase in malaria transmission (Hoshen & Morse, 2004), while dengue shows two peaks of incidence that correspond to the rain and warm-dry seasons (Watts, *et al*, 1987). Diarrheic diseases like cholera also show two peaks of incidence, one during spring and the second in the fall, because it is well documented that rain and warm temperatures influence the pathogen's survival and its transmission (Pascual, *et al*, 2002). An increase in temperature and water level can drive the rise of an infectious disease transmitted by water like cholera; likewise, an increase of sea level will reduce arable land, augmenting nutrition problems, which will generate changes in the immune response of people and an increased susceptibility to different infectious diseases.

The relationship between ecosystems, infectious disease, and climate change is more marked in developing countries like Mexico than in developed countries such as the US. Since in developed countries the quality of health services has improved, (i.e. access to quality drinking water), they have lowered the population's exposure to gastrointestinal pathogens and have better vector (arthropods) control programs, which reduce infectious diseases transmitted by such vectors. Developed countries also have a cold climate in general, which helps them to avoid the conditions favorable to the variety of vectors that transmit so called "tropical diseases". Curiously, developing countries are mainly in tropical and sub-tropical regions.

● EFFECT OF CLIMATE CHANGE ON INFECTIOUS DISEASES

Climate change can modify how infectious diseases are transmitted from animal or humans in three ways: a) increasing the reservoir animal or



FRESH VEGETABLES CAN BE A SOURCE OF INFECTIONS DUE TO IRRIGATION WITH CONTAMINATED WATER OR EXPOSURE TO RECREATIONAL WATER.

vector numbers, b) enlarging the transmission cycles, and c) importing vector or reservoir animals to new regions (Greer, *et al*, 2008).

According to the World Health Organization (WHO, 2005) the infectious diseases more related to climate are:

- Zoonotic diseases and those transmitted by vectors (dengue, Saint Louis encephalitis, yellow fever, malaria)
- Food and waterborne diseases produced by *Escherichia coli*, *Campylobacter*, *Salmonella*, *Shigella*, *Vibrio*, *Legionella*, *Clostridium botulinum*, *Giardia*, *Cryptosporidium*, hepatitis
- Respiratory diseases (influenza, *Streptococcus pneumoniae*)
- Fungi invasive diseases produced by *Blastomycosis*, *Coccidioides immitis*, *Cryptococcus gattii*.

● FOOD AND WATERBORNE DISEASES

Food and waterborne diseases are the main cause of mortality around the world and an important cause of morbidity in developing countries. In this group there are those produced by virus (Rotavirus and Norwalk virus), bacteria

GASTROINTESTINAL FOODBORNE DISEASES

REPORTED IN 2010 AN
INCREASE OF UP TO

20%



OF GASTROINTESTINAL
DISEASES AS A
CONSEQUENCE OF
HIGH TEMPERATURES,
HUMIDITY, AND WIND
IN THE HOT MONTHS
OF THE YEAR.

17

(*Legionella*, *Escherichia coli*, *Salmonella*, *Shigella*, *Vibrio*, and *Campylobacter*) or protozoan (*Giardia lamblia*, *Cryptosporidium*, *Entamoeba histolytica*). For example, *Campylobacter* and *Salmonella* are in the first places of incidence of foodborne disease in the US, according to the WHO (CDCc, 2014). On the other hand, a report of the National System of Health Information of Mexico's Ministry of Health (Sistema Nacional de Información en Salud-SINAIS, 2008), mentions that gastrointestinal diseases due to *Salmonella sp.*, *Shigella sp.*, Enteropathogen-*E. coli* (ETEC) or amoebas/worms are the 14th national cause of deaths and the main cause of child disease (four years old) and the fourth cause in children younger than a year (SINAIS, 2008); however, Aguilera and Marrufo (2007) and Duarte-Gómez, *et al.*, (2015), mention that these increase in low-resource areas without health services. A recent report informs that in 2014, the intestinal diseases (infectious and other non-defined diseases) are the second cause of morbidity in Mexico (Soto-Estrada, *et al.*, 2016).

Waterborne diseases can spread not only by drinking contaminated water, but also by eating different contaminated foods when these are not properly cooked or contaminated during preparation. Additionally, fresh vegetables can be a source of infections due to irrigation with contaminated water or exposure to recreational water (Rose, *et al.*, 2001). All these diseases can further be increased as a result of climate change, because many of the biggest outbreaks of these diseases have been related to extreme water precipitation and flooding. During the rainy season, where huge storms occur, the water volume can exceed the soil's draining capac-

ity and overflow wastewater treatment systems that can invade the regular water supply for cities (Rose, *et al.*, 2001; Hunter, 2003).

It has been registered that during hot seasons doctor's visits for gastrointestinal diseases increase up to 15% due to warm and hot weather. A higher temperature enhances the bacterial growth in food kept at room temperature (IMSS, 2010; Milazzo, *et al.*, 2016). Moreover, as the weather turns hotter, the ingestion of water increases without regard to water quality, which in developing countries usually does not have adequate sanitary conditions (Milazzo, *et al.*, 2016). This could explain why in those countries water and foodborne diseases are higher than in developed countries.

One of the routes of exposure to waterborne diseases is engaging in recreational activities, such as swimming and fishing, in contaminated waters. This leads to eye, ear, lung, and gastrointestinal infections (Wade, *et al.*, 2006). In addition, if climate change favors elevated temperatures, different pathogens that are usually absent, or have a low frequency in colder temperatures, will appear more often.

Another disease related to water is legionellosis, whose incidence is affected by climate change too. Legionnaire's disease (LD), a serious, sometimes lethal pneumonia, and Pontiac fever (PF), an influenza-like self-limited illness, are the two most common forms of legionellosis caused by *Legionella* bacteria. The peaks of incidence of this disease rise if the weather turns humid and the rain is more abundant because of the intensifying temperature (Fisman, *et al.*, 2005). The crude national incidence rate in the US increased 192%, from 0.39 per 100,000 ha-

SALMONELLA INFECTIONS ARE MORE RELATED TO AIR TEMPERATURE, AND IT IS BELIEVED THAT AROUND ONE-THIRD OF SALMONELLOSIS CASES CAN BE ATTRIBUTED TO TEMPERATURE INFLUENCE.

Water temperature (°C)	Average generation time (min)
15	174
17	157
20	132
23	106
25	90
27	73
29	56

Table 1. Generation time of *E. coli* at different growth temperatures in water in presence of organic matter.

bitants in 2000 to 1.15 in 2009 (CDCe and CDCf, 2014). Particularly, the east-south-central US had an annual incidence of 0.25 per 100,000 inhabitants in 2000, and for 2009 the incidence was 0.73 for the west-south-central (CDCf, 2014). This result was not associated previously with climate change but it should be analyzed. This could mean that if the weather changes to higher temperatures and humidity, the incidence of this disease will increase too.

● GASTROINTESTINAL FOODBORNE DISEASES

The Social Security (Health) Mexican Institute (Instituto Mexicano del Seguro Social, IMSS), reported in 2010 an increase of up to 20% of gastrointestinal diseases as a consequence of high temperatures, humidity, and wind in the hot months of the year. In Mexico, these infections are among the top ten causes of medical attention demand (IMSS, 2010). The gastrointestinal incidence behavior is similar in different countries regularly in tropical (warm) zones; however, in cold countries the gastrointestinal morbidity is low. Again, if climate change modifies the temperatures in these cold countries, the probability of gastrointestinal morbidity will increase too. Considering that in hot seasons high temperature favors strong winds and, as a consequence, the amount of dust in the environment increases, this condition, along with bad personal hygiene habits, poor sanitary con-

ditions on the street and food establishments, and higher consumption of contaminated water become the main factors that contribute to increasing the index of gastrointestinal infections like hepatitis and typhoid fever in Mexico (IMSS, 2009) or places with similar characteristics. At the same time, high temperatures improve the multiplication rate of pathogens, driving the number of pathogens in water or foods (Kendrovski & Gjorgjev, 2012) to reach the infective doses of bacteria that produce a disease.

According to the surveillance system of infectious disease outbreaks, foodborne diseases in the US during 2009-2010 registered 790 outbreaks of gastrointestinal illness; Norovirus caused 42% and *Salmonella* 30%, while 82% were produced by *Listeria*. Another study by Kistemann *et al* (2012) tried to find a relationship between climate change and the incidence of diseases transmitted by food and water; they concluded that the infections caused by *Campylobacter* were associated to air and water temperature, although this association was not always consistent. Nevertheless, there exists a better-known relationship with rainfall than with an increase of temperature.

On the other hand, *Salmonella* infections are more related to air temperature, and it is believed that around one-third of salmonellosis cases can be attributed to temperature influence. The relationship between salmonellosis and intense rain periods in regions with temperate and tropical climates has been documented extensively; however, there is little information about the presence of these bacteria in dry regions. In the study of Simental and Martínez-Urtaza (2008), on the coast of Baja California Norte, Mexico, the presence of *Salmonella* in coastal areas was demonstrated to be directly related to rainy periods and negatively to high temperature, probably due to the high solar radiation, which can affect the presence of these bacteria in the environment.

It is known that different chemical and physical factors, like ionic strength, organic concentration, pH, oxygen levels, temperature, water

CHOLERA



CHOLERA IS AN ACUTE DIARRHEAL INFECTION CAUSED BY WATER CONTAMINATED WITH THE BACTERIUM *VIBRIO CHOLERAE*

3-5 MILLION CHOLERA

CASES ARE ESTIMATED EVERY YEAR

AMOEBIASIS



IS CAUSED BY THE PROTOZOAN PARASITE *ENTAMOEBIA HISTOLYTICA*.

AROUND 10%

OF THE WORLD'S POPULATION IS INFECTED WITH THIS PARASITE, AND IN DEVELOPING COUNTRIES AND TROPICAL ZONES THE PREVALENCE CAN REACH 50 TO 80%.

activity, heavy metals presence, number and kind of microorganisms, etc., affect the growth of microorganisms. Temperature has a direct influence on the multiplication rate of different bacteria having a microorganism classification according to the optimal temperature growth as psychrophilic, mesophylls, and thermophiles organisms (Madigan, *et al.*, 2011).

- Psychrophilic: Microorganisms with the capability to grow below 0°C, although the optimum growth temperature is from 15°C to 20°C for obligated psychrophilic and up to 30°C for facultative. Examples of these microorganisms are *Flavobacterium* and *Polaromonas*.
- Mesophylls: Microorganisms with the capacity to grow between 25°C and 40°C, with optimum growth temperatures around 37°C. The majority of human pathogens belong to this group.
- Thermophiles: Microorganisms with an optimum growth temperature of 45°C. There are facultative thermophiles growing between 50°C and 60°C. The extreme thermophiles can grow at up to 113°C.

It is also well known that bacterial cells have an optimum temperature at which they reach their maximum division rate, which is defined by generation time. Higher values of generation time correspond to a slow division cell rate and vice versa. Therefore, at room temperature bacterial cells have a particular generation time and can divide faster (grow) if temperature increases. We wanted to know the difference when *Escherichia coli* is submitted at different temperatures in the presence of organic matter. In order to know that, a volume of 250 mL of *E. coli* was grown at different temperatures – 15, 17, 20, 23, 25, 27, 29°C – in 500 mL flasks containing distilled water and 0.1% of yeast extract (BBL) (to mimic the organic matter in water) and shaking at 2500 rpm in a water bath. The growth was measured by reading the absorbance at 600nm followed by 180 minutes to have an exponential growth. The absorbance was registered and the generation time of these bacteria was calculated (generation time is the time needed to duplicate its population) at each temperature. The results are depicted in table 1 and, as expected, at higher temperatures the bacteria grew faster. These data indicates that in



THE RAIN IN OCEANS PRODUCES A RISE IN THE TIDE LEVELS, WHICH LEADS TO FLOODS AND RAISING SALT WATER ON THE SHORES, FAVORING THE PRESENCE OF VIBRIO CHOLERAЕ IN NEW ZONES.

fact higher temperatures will affect the duplication time of *E. coli* and that this effect will be similar (proportional) for other pathogens as is discussed below.

● CHOLERA

Climate conditions affect not only the abundance of enteric bacteria in food or water, but also non-enteric pathogens that are present in the environment like *Vibrio*. Several species of this genus are autochthonous in estuary ecosystems and, depending on the water temperature, have different multiplication rates (generation time). *V. parahaemolyticus* and *V. vulnificus* are responsible for the most infections related to seafood consumption and in wound infections exposed to recreational water (Lipp *et al*, 2002). All *Vibrio* species including *V. cholerae* (responsible of cholera disease) are found practically in all water bodies, associated strongly to plankton in a commensal or symbiotic relationship, mainly with copepods and other crustaceous with chitin exoskeleton and with aquatic plants, protozoa, and bivalve organisms. All these organisms are reservoirs, and the main source of these bacteria spreading (Vezzulli *et al*, 2010). Changing the temperature of the environment will modify its propagation to new places where they did not exist before, and as a consequence these pathogens will appear in new geographic places considered cold.

Cholera is an acute diarrheal infection caused by ingesting food or water contaminated with the bacterium *Vibrio cholerae*. Around the world, 3–5 million cholera cases are estimated every year and 100,000–120,000 deaths occur due to this disease. In addition, it has a short incubation period, from two hours to five days, which enhances the potentially explosive pattern of outbreaks (WHO, 2008). Cholera is considered a re-emerging disease, possibly because it appears in new communities or in sites where it was absent for many years. However, this increase can be due to climate changes bolstered by conditions, which enhance the multiplication of this bacterium and its reservoirs. In a study by the International Centre for Diarrheal Research, Bangladesh (2009), a relationship was found be-

tween rainy seasons and cholera outbreaks because rainwater collects many nutrients in water bodies favoring the cholera reservoir.

Climate change due to global warming drives the increase of environmental temperatures and changes the rain patterns, together with increases in sea levels. This environmental temperature change increases the water temperature, enhancing the cholera bacteria multiplication. The rain in oceans produces a rise in the tide levels, which leads to floods and raising salt water on the shores, favoring the presence of *Vibrio* in new zones (CCC, 2009; De Magny & Colwell 2009). Actually, cholera is a rare disease in the US, having around six cases per year (Newton, *et al* 2011). Furthermore, *Vibrio parahaemolyticus* can produce outbreaks associated to the consumption of oysters, as reported in the northeast of US and in Galveston, Texas. In the Gulf of Mexico it is also prevalent (CDC, 1999; CDC, 1993).

● CRYPTOSPORIDIUM

Cryptosporidiosis is a disease transmitted fecal-orally and is characterized by sudden diarrhea. Although this enteric disease is not the most common or the most dangerous, it is especially dangerous because the cysts of *Cryptosporidium* are highly resistant to regular disinfectants. The parasite has low infective doses and, so far, there is no cure for this disease, which can be fatal to immunocompromised people.

Each year in the US, around 2 to 3 thousand cases appear by the ingestion of contaminated food or by drinking contaminated water from recreational swimming pools or lakes (Casman *et.al*, 2001). This parasite is spread by the oocyst, which is found commonly in wastewaters and in treated waters. At a temperature of 4°C the oocysts can survive up to four months and can lose its viability at freezing temperatures (-20°C) or at temperatures as high as 65°C (Becerril-Flores, 2014). According to the studies of Alum (2014), soil temperature is one of the main factors to keep oocysts of *Cryptosporidium* viability. It is interesting that at a temperature of 37°C a reduction of the oocysts was observed,

CRYPTOSPORIDIUM

Cryptosporidiosis is a disease transmitted fecal-orally and is characterized by sudden diarrhea.



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CASES APPEAR BY THE INGESTION OF CONTAMINATED FOOD OR BY DRINKING CONTAMINATED WATER.

while when the oocyst was kept at 15°C by 10 days, no reduction of viability was noted.

It has been observed that rain patterns affect the increase of cases of cryptosporidiosis (Casman, *et al*, 2001). All researches suggest that in low rain periods the oocysts of *Cryptosporidium* can be concentrated in underground water and, as rain falls, these oocysts are sent to water bodies that are commonly used for drinking (Lal, *et al*, 2013). This can explain why the number of cases is higher in the rainy season.

Some studies showed that a raise in environmental temperature, swollen rivers, and pollution could boost cryptosporidiosis. However, climate change by itself is not considered a good factor for predicting the disease, because the effects of climate can be halted by good practices in water treatment technology and good regulations for drinking water (Britton, 2010).

● AMOEBIASIS

Amoebiasis is caused by the protozoan parasite *Entamoeba histolytica*. This protozoan is a very common and cosmopolitan human pathogen, which is transmitted to people by drinking contaminated water and occasionally by contaminated food. Around 10% of the world's population is infected with this parasite, and in developing countries and tropical zones the prevalence can reach 50 to 80%. In Mexico, amoebiasis is still among the top 20 causes of morbidity, staying in the fifth place in 2003 and in the eighth place in 2008 (Sistema Nacional de Vigilancia Epidemiológica, 2011). In the

US, from 1990 to 2007, 134 deaths by amoebiasis were identified; however, a reduction in this period of 18 years has been observed. Close to 40% of fatal cases were reported among residents from California and Texas, most of them born outside of US (Gunther, *et al*, 2011). A study by the Department of Public Health of California in 2001, reported a prevalence of 1.63 cases per 100 000 inhabitants in the US-Mexico border region. This value dropped to 0.91 cases per 100 000 inhabitants in 2006. In the same study, it was noted that the higher prevalence was among Hispanic people, compared with white people in San Diego, California, but this difference is considerably reduced when the entire state of California was taken into account.

This parasite has two living forms: one is the vegetative form called trophozoite, which is responsible for the clinical form, and the resistant phase called cyst, which is the infective form. Water or food contaminated with cysts are the sources of infection for humans; after their ingestion the trophozoites are released in the intestine. However, many of these infections are asymptomatic, but in some individuals it can produce gastroenteritis by the destruction of the mucosal layer, with consequent diarrhea and cramps and, in some cases, can overgrow and invade other organs (Shimokawa, *et al*, 2012).

Amoebiasis is considered a waterborne disease too, and its spread is related to the water supply and its quality. The increase in water demand, and the deterioration of the accessibility of this resource, can lead the population to use

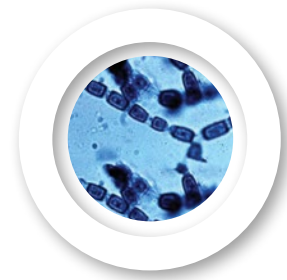
poor quality water. During floods, droughts, and earthquakes, which can damage treatment plants leading to water contamination, water adequate for human consumption diminishes. A study by Nichols, *et al*, (2009) found an association of different diarrhea outbreaks with polluted water for human consumption due to extreme climate, particularly water precipitation. If there are suddenly big rainstorms in dry places, rainwater runoff drags feces from animals or humans, carrying all contaminants to rivers or to underground water sources. This contamination is due to a loss in filtration capacity of the soil, passing all contaminants directly to underground water. If the source of water for human consumption is underground, and if this water is untreated, all waterborne diseases will increase.

● COCCIDIOIDOMYCOSIS

Coccidioidomycosis (CM) is a systemic fungal disease, endemic to desert zones of America, and produced by the dimorphic ascomycete fungus called *Coccidioides*. So far, two species, *C. immitis* and *C. posadasii*, have been identified. The most important zone for this disease involves the US-Mexico border, particularly the western region, and the most affected US states are California, Arizona, Texas, New Mexico, Nevada, and Utah. In the Mexican territory, the most affected states are Baja California, Sonora, Sinaloa, Nuevo León, Chihuahua, Coahuila, Tamaulipas, Zacatecas, and Durango (Bonifaz 2012). In Mexico, the actual situation for this disease is practically unexplored (Baptista *et al* 2007).

Recently, a relationship between diseases and atmospheric, climatic, and meteorological events has been noted (Kolivras and Comrie, 2003). Using models of environmental variables related to epidemiological information, Baptista-Rosas *et al* (2007) could identify the fundamental ecological niche of *Coccidioides* in arid soils and in North American deserts. In addition, these authors conducted a study to try to establish the relationship between climate and meteorological events and the epidemiological information available in Baja California, Mexico, finding that the higher number of cases of coccidioidomycosis occur during dry months preceded by rainy seasons (Baptista-Rosas *et al*, 2010).

Coccidioides is a fungus that adapts to survive in environments with low water availability, even though this fungus requires total humidity for germination and growth. For



COCCIDIOIDES IS A FUNGUS THAT ADAPTS TO SURVIVE IN ENVIRONMENTS WITH LOW WATER AVAILABILITY, EVEN THOUGH THIS FUNGUS REQUIRES TOTAL HUMIDITY FOR GERMINATION AND GROWTH.

spreading, it requires dry periods (Kolivras & Comrie, 2003; Comrie & Glueck, 2007). Two different bioclimatic patterns in the US-Mexico border have been observed. In Arizona, there is a relationship between the number of clinical cases and weather events, while in California this association is not constant suggesting that the higher prevalence of the disease is more related to other factors of anthropogenic source (Baptista 2010, Zender & Talamantes 2006). However, if climate changes in the future increase or reduce humidity, the fungus development (depending on a particular genus) will increase or decrease. Specifically, coccidioidomycosis will increase, as this fungus is from desert places.

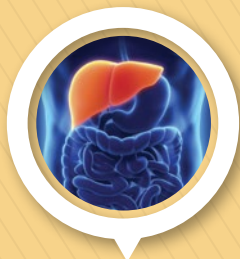
● VIRAL INFECTIONS

Virus are considered strict parasites that need to be inside of the cell in order to use the metabolic cell system to reproduce. Virus are conformed by nucleic acid (DNA or RNA) and surrounded by a protein layer called capsid. A second membrane envelops some virus. The naked virus (without an external membrane) are potentially more resistant to the environment, helping the virus to be viable for several weeks and keeping their capacity to infect and multiply in animals or humans, such as the virus that cause gastroenteritis, and particularly the enterovirus. The enveloped virus, in general, are more sensitive to the environment and this virus is not the exception and must be transmitted by direct contact among individuals or by vectors (Schvoerer, *et al*, 2008). Global warming, as mentioned



A RELATIONSHIP BETWEEN DISEASES AND ATMOSPHERIC, CLIMATIC, AND METEOROLOGICAL EVENTS HAS BEEN NOTED (KOLIVRAS AND COMRIE, 2003).

HEPATITIS A



THIS VIRUS INFECTS THE LIVER, AND THE INFECTION MAY BE EITHER ICTERIC OR ANICTERIC.

ICTERIC

In children younger than 6 years old, more than 90% of hepatitis A infections are asymptomatic.

VIRAL INFECTIONS

THREE MECHANISMS CAN EXPLAIN THE INFLUENCE OF RH AND TEMPERATURE ON VIRAL TRANSMISSION.

1

Cold air can cause a dry nasal mucosa in the host, which leads to a higher susceptibility to viral infections.

2

The virus stability is highest at a RH between 20%-40%, medium at RH of 50% and minimum at 60%-80% of RH.

3

The third mechanism is related to bio-aerosols.

before, can produce increased rainfall in some places, while in others it will increase dryness. Rainfall and its accumulation favor conditions for mosquitos to multiply and several of their species can be the vector of many viral diseases. An increased multiplication of a particular mosquito (vector) can promote the transmission of different vector-borne diseases like dengue, zika, chikungunya, etc. Barrera *et al* (2011) observed that rainfall is associated with an increase in the vector population of dengue (*Aedes aegypti*) since water containers in many houses are the ideal sites for developing larvae, pupa and producing adult mosquitos. On the other hand, intense rainfall can wash away completely the containers with a negative effect in the vector population.

An increase in temperature accelerates water evaporation, limiting the number of water reservoirs that can act as habitat for immature mosquitoes. Even when the eggs are resistant to desiccation for long periods, mosquito development can be affected (Morin, *et al* 2013); but when precipitation is higher than evaporation mosquito reproduction will be higher. By contrast, in dry periods people habitually store water in open cisterns or containers that favor the development of mosquitos.

Climate change will also have an indirect impact on the distribution of viral diseases. Urban concentration facilitates the contact between humans, animals, and polluted water, spreading enteric and respiratory diseases as it happens with the influenza virus. The transmission of this virus is more prevalent in the cold seasons, when people prefer to congregate in closed sites. Lowen, *et al* (2007) demonstrate that the influenza virus is dependent on relative humidity (RH) and temperature. In an animal model, transmission of the influenza virus was highly efficient at low RH (20-35%) and at low temperatures (5°C).

Three mechanisms can explain the influence of RH and temperature on viral transmission. First, cold air can cause a dry nasal mucosa in the host, which can produce epithelium damage with consequent reduction of the mucocilia layer, which leads to a higher susceptibility to viral infections. Secondly, the virus stability is highest at a RH between 20%-40%, medium at RH of 50% and minimum at 60%-80% of RH. The third mechanism is related to bio-aerosols; at high RH, respiratory droplets take water from their environment and increase their size, falling down faster, while at low RH water evaporation exists, which drives lower droplet forma-

tion favoring its presence in the air for a longer time (Lowen, *et al* 2007, Fuhrmann 2010).

Another factor that must be taken into account is viral inactivation by UV radiation, which can be modified by climate change. This factor plays an important role in rising influenza outbreaks. Low exposure to solar radiation favors the viability of the virus for several days after its release by a host. This situation is present in the rainy season due to an increase of cloud cover, and in dry seasons, when cases of wildfires produce smoke that also limit UV radiation. (Sagripanti & Litle, 2007).

● HEPATITIS A

One virus related to water is the hepatitis A virus (HAV), which is an RNA virus belonging to the Picornaviridae family. This virus infects the liver, and the infection may be either icteric or anicteric. The likelihood of icteric (clinically apparent) disease is inversely related to the age of the person acquiring HAV. In children younger than 6 years old, more than 90% of hepatitis A infections are asymptomatic. By contrast, more than two-thirds of older children and adults will develop jaundice after a hepatitis A infection (Lednar *et al.*, 1985). This disease is transmitted mainly when a healthy non-vaccinated person consumes food or water contaminated with human feces from a person infected with HAV. The disease is closely related to the lack of clean water and low sanitary infrastructure joined to bad personal hygiene (WHO, 2014). The waterborne outbreaks of HAV, although slightly frequent, are related to water contamination from wastewater or water sources with deficient quality treatment.

In the US, this disease is under control due to a vaccination program established in 1995 and applied in all American states with higher incidence (Committee on Infectious diseases, 2007). This report shows how the incidence of HAV dropped below 5% in 1999. It is worth noting that in this analysis the incidence of HAV, according to the race/ethnicity in the US, was higher in the Hispanic group and, certainly, the bigger proportion of Hispanic people is found in the border region.

In regions with temperate climate, outbreaks of entero-virus appear during the summer and early fall seasons. These outbreaks suggest that temperature and relative humidity (RH) are important for this seasonality. However, particularly for HAV, cases appeared in some



THE WATERBORNE OUTBREAKS OF HAV, ALTHOUGH SLIGHTLY FREQUENT, ARE RELATED TO WATER CONTAMINATION FROM WASTEWATER OR WATER SOURCES WITH DEFICIENT QUALITY TREATMENT.

places not related to the season, or more related to wintertime.

In the study of Mbithy *et al* (1991), it was observed that HAV survival – meaning that the virus has a longer lifespan – was inversely proportional to RH and temperature. They found that the lifespan of HAV was seven days at low RH (25%), and 5°C, while at high RH ((95%) and 35°C it was two hours. This behavior is different from other enteroviruses that have a better survival rate at higher temperatures. Another issue to consider is UV radiation, which is expected to increase too; this radiation may promote mutations in the RNA genome that favor the origin of new strains for which the current vaccines will not prevent the disease.

The incidence of the diseases mentioned above will be affected by climate change. The analysis of the local climate change will give us an explanation of the emergence or re-emergence of these diseases. It is a fact that the cooperation and intervention of different disciplines and experts are needed: physicians, biologists, climatologists, epidemiologists, and certainly people involved in politics, infrastructure development, and government with all its secretariats. Understanding the relationship between climate change (events increasing or decreasing above or below the regular average behavior), emergence, and re-distribution of the diseases, will require establishing stronger strategies to prevent large-scale catastrophes in the near future.



THE INCIDENCE OF THE DISEASES WILL BE AFFECTED BY CLIMATE CHANGE. THE ANALYSIS OF THE LOCAL CLIMATE CHANGE WILL GIVE US AN EXPLANATION OF THE EMERGENCE OR RE-EMERGENCE OF THESE DISEASES.

CONCLUSIONS

Over the past decades, there has been renewed public and official concern about infectious diseases as a major public health threat. This depends on the type of disease (classical, emerging or re-emerging), location, and the country's development. However, in spite of all efforts, we are not yet prepared to face climate change, which clearly will raise global temperatures. Overheating will affect the amount of rainfall, producing floods or droughts depending on the region, and altering the local weather. This means that infrastructure in cities and counties – and people – might not be prepared for these changes.

One of the main changes will be in the environment's soil, water and air temperatures. These changes will favor the growth of different plants, insects, and microorganisms – in particular, human pathogens – without taking into account the danger from other species. Increasing the speed of growth, in most cases reaching the infective doses of different pathogens, or favoring the generation of new mutations of all parasites (i.e. the drug resistant), or in the case of viral diseases the emergence of new strains against which existing vaccines will not work and health systems will be insufficient to control future outbreaks.

Active participation of the population will be important for making decisions and assuming actions towards planning and improving infrastructure in all regions, because climate change will affect the entire planet without exception. Participation should be strategically led by local authorities, and supported at federal levels, to achieve the expected environmental goals through law enforcement and by creating incentives. Another key strategy is the inclusion of different experts in areas such as medicine, biology, construction (houses, draining systems, water collecting, roads, bridges, etc.), economics, anthropology, among others, in order to have a better understanding and finding the best options to face future problems in a holistic way.



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