CLIMATE CHANGE AND ITS IMPACT ON HUMAN HEALTH IN MEXICO

ABSTRACT

Climate change is affecting health in a variety of ways, including deaths and illness from extreme weather events, heat waves, storms and floods, the disruption of food systems, an increase in zoonoses and food, water and vector-borne diseases, mental health problems and environmental migration. It is also undermining social determinants of good health, such as livelihoods, equality and access to health care and social support structures. These risks disproportionately affect the most vulnerable and disadvantaged people (women, children, ethnic workers, poor communities, migrants and/or displaced persons, older adults and people with underlying health conditions). The objective of this study is to present a set of regional projections of temperature, rainfall, humidity and Standardized Precipitation Evapotranspiration Indices (SPEI) drought index for Mexico under the sixth evaluation cycle (AR6) climate change scenarios of the (Intergovernmental Panel on Climate Change (IPCC), improving the projections of the Ocean-Atmospheric General Circulation Models and estimating the possible impacts of climate change on the health sector of Mexico. Regional models for Mexico show temperature increases ranging from 0.5 to 5 °C, while % precipitation anomaly will range from -20.3 to 13.5% depending on scenario and period of analysis. The low soil moisture, the negative changes of Normalized Difference Vegetation Index (NDVI) and SPEI 12 show that the North, West and Bajío zones presented reductions in precipitation and temperature increase that caused soil moisture deficit, water stress, presence of scarce vegetation and semi-permanent meteorological drought. Under these scenarios, it is expected that the entire country will be subjected to moderate to extremely strong droughts that will last and worsen between now and the end of the century. The results of the scenario projections and forecasts made by the IPCC show that diseases associated with climate change have already been present for several decades in Mexico and are expected to worsen by the end of the century, with consequent increases in health expenditures. It is estimated an increase in Gross Domestic Product (GDP) investment in the health sector that would go from the current 6.25% to more than 18%, while per capita spending will increase from $ 1230 US dollars to more than $ 3800 dollars at the end of the century, which could perhaps be unfeasible for the national economy, since it is estimated that productivity in the three sectors would be substantially reduced by the end of the century by the same effects of climate change. Thus, the vulnerability of the health sector in Mexico is high to very high, which puts the population at high risk. IPCC (Intergovernmental Panel on Climate Change);

Keywords: Health, climate change, respiratory diseases, cardiovascular diseases, food security and malnutrition.

1. INTRODUCTION

Rising greenhouse gas (GHG) emissions are increasing the planet's temperature and causing climate change. The consequences include melting glaciers, rising sea levels, increasing/decreasing precipitation depending on the area of the planet and high frequency of extreme weather events with changes in the weather seasons. The accelerating pace of climate change, coupled with population growth, threatens the climate and the health of the world's populations.

Climate change is currently an important component in public health, since its effects have a direct and indirect impact on the determinants of people's health (biological, environmental, physical, social, lifestyle and health services). The effects of climate change are causing an accelerated deterioration of environmental health, which in turn gradually encourages an increase in diseases caused by environmental factors.

Vulnerability to climate change is the degree to which a natural or social system could be affected by environmental changes. Thus, a vulnerable system is one that is very sensitive to small changes in climate, including the possibility of suffering very harmful effects, or one whose ability to adapt is seriously limited. Vulnerability is framed in a scenario of inequalities, due to the enormous gaps between rich and poor countries, which further accentuates the problem of confronting climate change. All populations will be affected by climate change, but the most vulnerable regions will feel the effects to a greater degree. Thus, children and women in poor countries are one of the most vulnerable populations to the health risks resulting from climate change and will also be exposed for longer to the consequences of it. What countries with poor health infrastructure (underdeveloped countries) are the ones that will have the most difficulties in responding to the health problems generated by climate change [1].

This research aims to highlight the impacts of climate change on the health sector in Mexico, such as the influence of extreme temperatures that contribute to deaths from cardiovascular and respiratory diseases, the increase in the incidence of vector-borne diseases, air pollution by aerosols and allergens, which can increase cases of respiratory diseases, reduction of water resources, which jeopardize the availability of drinking water and efficiency of drainage systems, increased incidence of diarrhea and gastrointestinal diseases, deterioration of food quality and quantity, malnutrition, deficiency diseases and poisoning, the thinning of the ozone layer with the consequent increase in skin cancer and dermatological problems, massive migrations due to climate change, such as extreme weather events, which increase the number of injured, deceased, and diseases, among others, which will generate the collapse of health systems. This analysis uses regional modeling of climate variables under climate change conditions that impact the health sector, using two scenarios to simulate future climate.

BACKGROUND

The second IPCC report (1995) indicates that climate change is very likely to have significant adverse effects on human health, with significant loss of life. It indicates that health disruptions caused by climate change depend on several factors that coexist and interact determining vulnerability: socioeconomic development, environmental context, diet, immunization system, population density, and access to quality health services[2]. The third IPCC report (2001) concludes that there would be an increase in the incidence and seasonality of infectious diseases such as malaria and dengue, indicating that the occurrence of these diseases is influenced by local environmental conditions, socio-economic circumstances and public health infrastructure. It also suggests some adaptations to address the health effects of climate change include: strengthening public health infrastructure, management oriented towards environmental health and provision of adequate health care facilities [3]. The fourth IPCC report (2007) notes that projected health impacts of climate change are predominantly negative, especially in low-income countries, where adaptive capacity is weaker [4]. The fifth report (2014) proposes that this phenomenon can impact health, directly and indirectly, through the increase of social, economic, and political inequality gaps in the regions. Indicating specific impacts of climate change with health problems, such as mortality associated with extreme weather events, heat and cold waves; waterborne diseases, increased frequency of diarrhea in children under 5 years of age during the rainiest and driest seasons in tropical areas; the adaptation of the mosquito to dengue and vector-borne diseases, which inhabit urban spaces, where they did not exist before, as a result of the warmer environment due to the increase in global temperature; deterioration of air quality by pollutants such as ozone (O_3) and particulate matter ($PM_{2.5}$) emitted by internal combustion vehicles that cause between 86400 and 89100 premature deaths worldwide annually, emphasizes the need to develop and implement adaptation strategies, policies and measures at different levels, indicating that current national and international programs together with measures aimed at reducing the burdens of health-sensitive determinants climate and outcomes need to be revised, reoriented and scaled up to address the additional pressures of climate change [5]. The sixth IPCC report (2022) mentions that climate change has negatively affected the physical and mental health of people around the world and in the regions assessed. Health impacts are mediated by natural and human systems, including economic and social conditions and disruptions. In all regions, extreme heat events have caused human mortality and morbidity. The incidence of climate-related foodborne and waterborne illness has increased. The incidence of vector-borne diseases has increased due to the expansion of the range and/or the increase in the reproduction of disease vectors. Animal and human diseases, including zoonoses, are emerging in new areas. The risks of waterborne and foodborne diseases have increased regionally due to climate-sensitive aquatic pathogens and toxic substances from harmful freshwater cyanobacteria. Although diarrheal diseases have declined globally, higher temperatures, increased rainfall and flooding have increased the occurrence of diarrheal diseases, including cholera and other gastro-intestinal infections. Some mental health problems are also associated with increased death, trauma from extreme weather events and loss of livelihoods and culture. Increased exposure to wildfire smoke, atmospheric dust, and aeroallergens have been associated with climate-sensitive cardiovascular and respiratory distress. Health services have been disrupted by extreme events such as flooding [6].

The World Health Organization (WHO, 2010), points out that climate change influences the basic requirements of health: clean air, drinking water, sufficient food, and safe housing. Reducing greenhouse gas emissions through improvements in transportation and food choices and energy use can translate into health improvements. The measurement of the health effects of climate change can only be done approximately. However, the WHO concluded that the modest warming recorded since the seventies was already causing excess mortality of around 140 000 deaths per year in 2004 and 5 million disability-adjusted life years [1].

It is generally estimated that climate change may affect health due to:
Air pollution: Climate change is caused by an increase in GHGs in the Earth's atmosphere, mainly carbon dioxide resulting from fossil fuel emissions, it can also have direct consequences for human health, because polluted air contains small particles that can induce strokes and heart attacks by penetrating the lungs and the heart and travel to the bloodstream. Those particles can damage organs directly or trigger an inflammatory response from the immune system when it tries to fight them. Estimates suggest that air pollution causes between 3.6 and 9 million premature deaths per year. People over 65 are more susceptible to the harmful effects of air pollution, but other groups are also at risk such as smokers, children with asthma and allergy sufferers. Carbon dioxide increases the acidity of the air, which then extracts more pollen from plants which for some people, could mean annoying and prolonged episodes of seasonal allergies. Climate change is also causing more intense and prolonged wildfires and their smoke is especially toxic, as it contains tiny particles from the combustion of countless harmful chemicals that can penetrate deep into a person's lungs and organs.

Extreme heat: Vicedo-Cabrera et al. (2021) attribute more than a third of heat-related deaths produced by climate change. The human cost is higher in countries with less access to air conditioning or other factors that make people more vulnerable to heat. The human body is not designed to cope with temperatures above 37 ºC. The body has some ways of dealing with heat, such as sweating. However, if you are exposed to extreme heat for too long and cannot be released, stress can cause many problems in the body [7]. The heart has to work harder to pump blood to the rest of the organs, while sweat absorbs necessary minerals such as sodium and potassium from the body, which can lead to heart attacks and strokes. Dehydration from heat exposure can cause serious damage to the kidneys, which depend on water to function properly. For older adults with kidney problems, extreme heat is a death sentence. Links have also been shown between higher temperatures and premature births and pregnancy complications, probably because extreme heat reduces blood flow to the fetus.

Food insecurity: One of the least direct, but no less harmful, ways climate change can affect health is the disruption of the global food supply, as it reduces the amount of food available and makes it less nutritious. According to a special report by the IPCC (2019), crop yields have already declined as a result of rising temperatures, changes in precipitation patterns and extreme weather events [8]. It has shown that increasing carbon dioxide in the atmosphere can remove zinc, iron and proteins from plants, nutrients humans need to survive. Malnutrition is linked to a variety of diseases, including heart disease, cancer, and diabetes, and can increase the risk of stunted or impaired growth in children, which can impair cognitive function. Climate change also threatens seafood; the rising ocean temperature has led many species to migrate poleward in search of cooler waters. Declining fish populations in subtropical regions have major implications for nutrition, as many coastal communities rely on fish for a substantial amount of protein in their diets.

Infectious diseases: As the planet warms, the geographic region that is comfortable habitat for ticks and mosquitoes becomes wider. These are well-known vectors of diseases such as Zika, dengue, chikungunya, malaria, among others. As they cross the tropics of Cancer and Capricorn, mosquitoes and ticks provide more opportunities for these diseases to infect large swaths of the world. In addition, weather conditions such as temperature and humidity can affect the life cycle of mosquitoes. In some regions, climate change has altered conditions in ways that increase the risk of transmitting mosquitoes. It is also increasing the risk of waterborne diseases, such as cholera, typhoid, and parasites, directly when people interact with contaminated water; or indirectly to, in drought when it is not possible to wash your hands or the only option is to drink from unknown sources.

Mental health: A common outcome of any climate-related disaster is mental health, such as distress caused by drastic environmental change. Extreme weather events, such as wildfires and hurricanes, cause so much stress and anxiety that they can lead to Posttraumatic Stress Syndrome (PTSD) and even suicide. The mental health effects have an immediate psychological impact on wildfires when people lose their homes, jobs and loved ones.

Moreover, the effects of climate change do not occur in isolation. A community can face air pollution, food insecurity, disease and extreme heat at the same time and it is devastating in communities where the prevalence of food insecurity and poverty is already high.

WHO (2021) has made some future projections of the health impacts of climate change: Climate change is projected to cause an additional 250 000 deaths per year due to malnutrition, malaria, diarrhea and heat stress between 2030 and 2050. The cost of direct damage to health (i.e. excluding costs in health-determining sectors such as agriculture, water and sanitation) is estimated to be between US$ 2 billion and US$ 4 billion per year by 2030 [1].

The IPCC has concluded that to avoid catastrophic health impacts and prevent millions of climate change-related deaths, the world must limit temperature rise to 1.5 °C. Past emissions have already made some level of global temperature rise and other climate changes inevitable. However, a global warming of 1.5°C is not considered safe; every tenth of a degree of additional warming will have a serious impact on people's lives and health. While no one is safe from these risks, the people whose health is being harmed first and most severely by the climate crisis are those who contribute least to its causes and are least able to protect themselves and their families: people in low-income and disadvantaged countries and communities.

The climate crisis threatens to undo the last fifty years of progress in development, global health, and poverty reduction, and to further widen existing health inequalities between and within populations, seriously jeopardizing the realization of universal health coverage by aggravating the existing disease burden and exacerbating barriers to accessing health services, often at times when they are needed most. More than 930 million people (12% of the world's population) spend at least 10% of their household budget paying for health care. With the poorest largely uninsured, health-related crises and stresses push some 100 million people into poverty each year and the effects of climate change worsen it.

Effects of Climate Change and the Related Health Risks in Mexico

COFEPRIS (2017) mentions that in Mexico the health risks derived from the effects of climate change already manifested and that could worsen between now and the future are [9]:

List 1. Effects of Climate Change and the Related Health Risks in Mexico

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	Effects of Climate Change	Derived Health Risks
Extreme events	Increase in the frequency, duration and intensity of heat waves	• Increased cardiovascular and respiratory mortality linked to heat inolder, sick and debilitated people.
	Possibility of significant cold peaks	• Increase in cardiovascular and respiratory mortality linked to cold in the elderly, sick and debilitated, children and young people
	More frequent droughts	• Increase in waterborne diseases • Increase in diseases and food outbreaks • Increased risk of wildfires (respiratory and cardiovascular problems) • Agricultural productivity problems: rising prices or insufficient food in extremes • Impact on mental health.
	Tendency to increase torrential episodes and consequent floods	• Direct effects: drowning, injury, diarrhoea, vector-borne diseases, respiratory infections, skin and eyes, mental health problems • Damage to drinking water supply and sanitation systems, crops, housing, alteration in living conditions and mobility of the population • Damage to the equipment and endowments of the health care system
Water & Food	Contamination of water supply and water used for recreational purposes.	• Increase in diseases and seasonal outbreaks of water transmission. • Increased exposure to biological and chemical contaminants.
	Reduction of net water inputs and increase in demand.	
	Impact on the distribution, seasonality and transmission of foodborne diseases.	• Increase in foodborne diseases.
	Increased transport and spread of human pathogens from continental areas to coastal and estuarine areas (from storms and floods).	• Contamination of marine products by marine toxins and pathogens and by human or animal contamination. • Poisonings related to the preservation of different marine products.
	Changes in environmental and oceanographic variables (temperature and salinity).	
	Upwelling of toxic algae and bioaccumulation in marine products for human consumption.	
Vectors	Modifications in vector capacity.	• Changes in the incidence and distribution of vector-borne diseases.
	Appearance of potential breeding foci (Post extreme rainfall).	

Air pollution	Higher concentration of pollutants in the air. Particulate matter and ozone are the most significant.	• Increase in hospital admissions for respiratory and cardiovascular diseases • Increased mortality
Pollen	Increased production of pollen and fungal spores. Longer pollen stations. Changes in the geographical distribution of allergenic pollen-producing species.	• Exacerbation of allergic respiratory diseases such as allergic rhinitis and asthma.
Rad. UV	Increased exposure to UV radiation.	• Cancers and diseases of the skin, cataracts, eye damage. • Immunological effects.

2. MATERIAL AND METHODS

Climate change scenarios at the regional level provide the information needed to estimate the potential impacts of extreme weather on the environment and human activities [6]. Scenarios should not be tacitly considered as predictions or forecasts, but as consistent visualizations of possible future climates, responding to the increase in radiative forcing. This is very important since climate at the regional level can be affected by other variables that are not included in global models and climate projections such as the effects of land use change, tropical cyclones, among others.

Ocean-Atmosphere Global Circulation Models (AOGCM) do not have sufficient spatial resolution to represent some atmospheric processes of relevance to the regional climate of tropical areas (e.g., tropical cyclones) or land surface processes that determine the unique regional heterogeneity of Mexico's climate. Thus, biases in simulations and the limited number of high spatial and temporal resolution experiments, either with nested models or statistical techniques, affect confidence regarding regional and local precipitation and temperature scenarios. Therefore, the approach of obtaining regional scenarios focuses on reducing systematic errors in AOGCM to reach an adequate estimate of the expected ranges of change due to increased GHG concentrations.

Due to the thick scale at which AOGCMs operate, geographic locations of coasts or mountain ranges may be distorted, inducing systematic discrepancies in regional climate simulations. These discrepancies can propagate in regional climate change scenarios if simple linear interpolation is used as a downscaling tool. Therefore, AOGCMs need to be adjusted so that they can be interpolated at the regional level. CMIP6 (Coupled Model Intercomparison Project Phase 6) [10] was developed by the World Bank to statistically reduce discrepancies in climate model production from seasonal and regional climate predictions for regional model validation. The spatial resolution fields of the coarse climate model of temperature and precipitation are approximately 300 × 300 km and can be reduced to finer spatial scales of the order of 100 × 100 km, comparable to observed analyses of the regional climate.

Downscaling techniques (global to regional) calibrate statistical transfer functions through historical relationships between modeled and observed fields to reduce systematic errors in model output. The identification of such errors is best achieved when not only grid points but also patterns and modes of variability are correlated [11]. CMIP6 scenarios form the database of the IPCC Assessment Reports and were therefore used to develop regional projections.

The IPCC's integrations for climate change studies span from 1900 to 2100, allowing transfer functions to be built using the high spatial resolution of the temperature and precipitation fields observed for the period 1900-2020. In the present analysis, the stability and ability of the transfer function are assessed using data from 1995-2014 as the reference period. As with any method of bias correction, the quality of observational datasets limits the quality of bias correction. In addition, it is assumed that the bias behavior of the model does not change over time; therefore, in downscaling, relationships are assumed to be stable in a changing climate. It is important in downscaling climate change scenarios [12].

Various statistical approaches have been proposed to reduce the scale of AOGCM climate change scenarios for Mexico to project the activity of medium, and even extreme events [13-14]. However, most of these are based on few models and lack the benefit of a multi-model overview such as that presented at the IPCC AR6. AOGCM climate change scenarios used in the IPCC AR6 model projections of temperature and precipitation are available from the IPCC Data Distribution Centre. The multi-assembly model output fields for the radiative forcing scenarios of SSP1 (Sustainability - Taking the green road - low challenges to mitigation and adaptation) SSP1-1.9, SSP1-2.6 , SSP2-4.5 (Middle of the road - medium challenges to mitigation and adaptation), SSP3-7.0 (Regional rivalry-A rocky road - high challenges to mitigation and adaptation), and SSP5-8.5 (Fossil-fueled development - Taking the highway - high challenges to mitigation, low challenges to adaptation) have been reduced with the CMIP6 scenarios. CMIP6 reference scenarios for each AOGCM were used to construct projected changes in regional climate.

In the downscaling process, the monthly observed temperature and precipitation fields of the Climate Research Unit (CRU) of the University of East Anglia were used, with a spatial resolution of 50 x 50 km for the period 1901-2020 [15]. CMIP6 data capture Mexico's low-frequency variability and temporal temperature and precipitation trends.

In the present study, climate projection data are modeled data from global climate model compilations from Coupled Model Intercomparison Projects (CMIPs). The data presented are CMIP6, derived from the Sixth phase of the CMIPs that form the database of the IPCC Assessment Reports. This climate predictability tool, used as a statistical method of downscaling, allows the preparation of regional climate change projections to estimate the spread between models as a measure of uncertainty in projected changes in climatological variables. In this way, changes in temperature, precipitation, relative humidity, and annual drought index for this century are obtained and together with vulnerability projections, the potential impacts on the health sector in Mexico are estimated. The projection data is presented with a resolution of 1.0°x1.0° (100km x 100km).

The ability to generate scenarios over a long period allows to reproduce climate parameters and the response of regional climate to large-scale forcing, such as increased radiative forcing, resulting from increased GHG concentrations. Thus, the estimated trend of temperatures, relative humidity, precipitation, and annual drought index SPEI was obtained on a regional scale for Mexico between 2020 and 2099.

Other analyses were used to determine environmental health impacts such as the Normalized Difference Vegetation Index (NDVI), which was taken from the NASA data archive [16]. The NDVI is used to assess the impact of abnormal climatic conditions on vegetation and is a measure of the amount and vigor of vegetation on the soil surface. The index ranges from −1.0 to 1.0, with negative values indicating clouds and water and positive values close to zero, indicating bare soil, and higher ranging from sparse vegetation (0.1−0.5) to dense green vegetation (0.6 and above). Because NDVI is an indicator of the amount and vigor of vegetation greenness, positive anomalies correspond to healthy vegetation conditions and negative NDVI anomalies correspond to stressed vegetation. We also used Standardized Precipitation Evapotranspiration Indices (SPEI), which is an indicator of precipitation-derived drought, which calculates drought based on the standard deviation of long-term cumulative mean precipitation, including evapotranspiration. Positive values indicate positive water balance (wet conditions), and negative values indicate negative water balance (dry conditions). This indicator shows the frequency and intensity of droughts observed lasting 6 and 12 months. Longer periods can be used to indicate risks associated with prolonged hydrological drought, such as reduced reservoir recharge and water availability. Temperature increases generally increase moisture and precipitation losses and therefore increase the risk of drought. This indicator should be used with caution in typically arid regions and dry seasons. The reference period for calculating the SPEI indicator is 1981-2010. Soil moisture ($metre^3/metre^3$) was also estimated, showing the average water content of the topsoil (0 to 5 cm deep), and used as an indicator of the extent and duration of drought. There is a strong interrelationship between soil moisture, vegetation, and climate in the short and long term. Soil moisture influences the type and condition of vegetation and, in turn, evapotranspiration. Change in soil moisture can have considerable impacts on agricultural productivity, ecosystem health, livestock development, food security and human health. Soil moisture data can be used to anticipate and manage risks related to drought and secondary hazards (e.g., wildfires), and guide resilience programming in long-term food production to generate food security and reduce malnutrition and related health problems. Finally, this information will be complemented by maps of drought episodes in Mexico in recent decades.

3. RESULTS AND DISCUSSION

Figure 1 presents the climatology for Mexico in the period 1991-2020, the data present a resolution of 0.5° x 0.5° (50 km x 50 km) for a) average annual temperature (21.27±4.11°C), b) accumulated annual precipitation (898.54±45.21 mm), c) minimum temperatures (13.69±4.03 °C), maximum (28.89±4.02 °C), monthly precipitation (74.88±41.47 mm) and d) relative humidity (57.96±6.43%).

The trend to change in temperature, relative humidity and precipitation are a measure of climate sensitivity to increased radiative forcing that has increased in recent years, forcing warmer weather [6]. The regional linear trend over Mexico in the period 1991-2020 is captured by the CMIP6 regional set of climate change scenarios.

Regional climate change scenarios

Most studies agree that temperature will increase in the coming decades, affecting the hydrological cycle on a global and regional scale [4, 6, 17]. The impacts of climate change are expected to have a large number of consequences, particularly in the health sector in regions of developing countries where climate disasters have also occurred in recent decades. The IPCC (2007, 2021) has concluded that Mexico will be among the regions where the water deficit will be exacerbated due to increases in temperature, reduction of relative humidity and rainfall, increasing drought, extreme events, affecting food production and supply and consequently the health problems of population [4, 6]. The regional scale climate change scenarios obtained through CMIP6 are able to show the contrasts in projected climate changes between regions of Mexico.

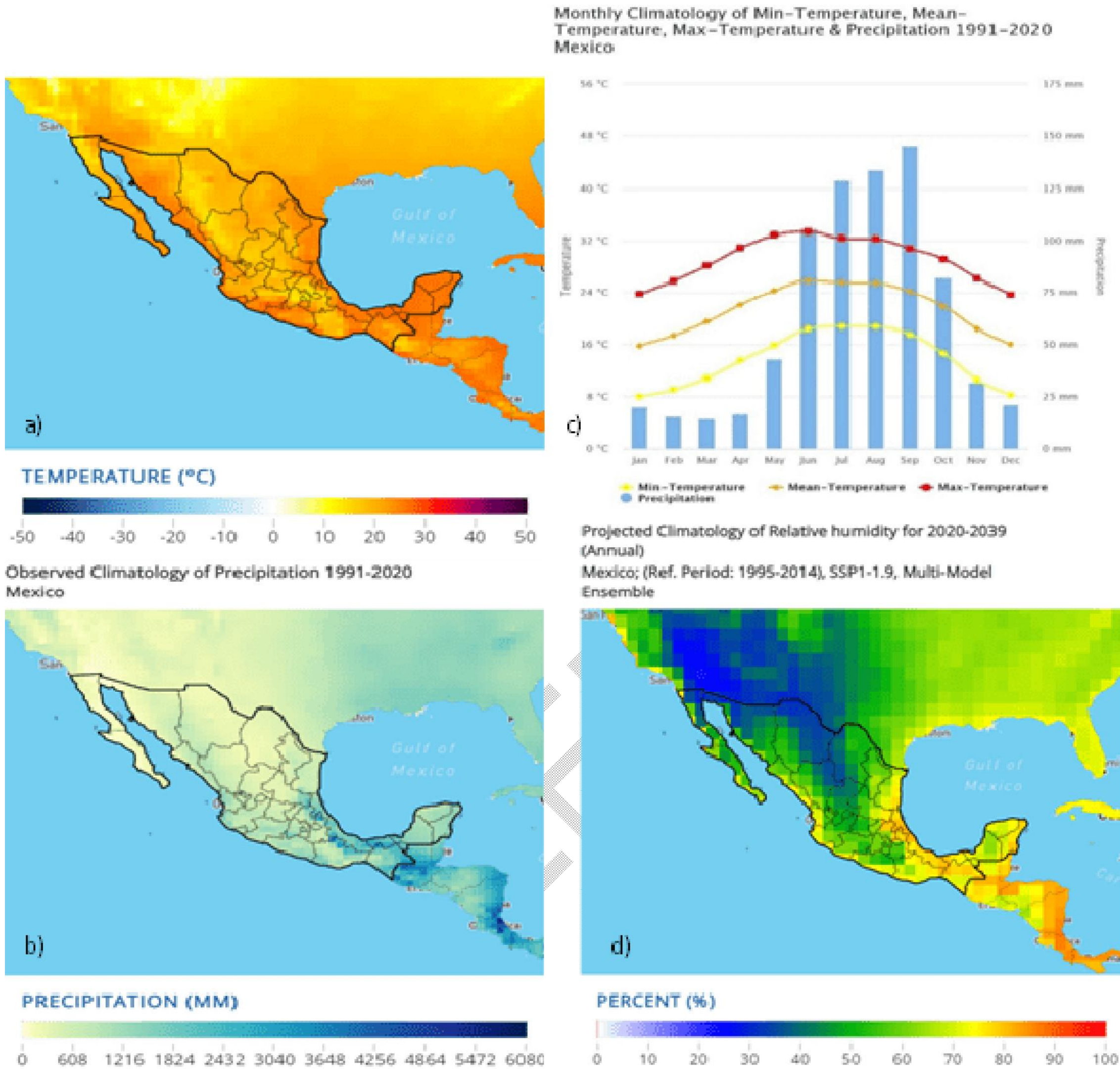

Fig. 1. Climatology with CRU data (50 × 50 km) (base period 1991-2020) observed of a) average annual surface temperature, (b) average annual precipitation (mm), (c) minimum, maximum, average, and monthly precipitation; and (d) relative humidity (CCKP, 2022).

Regional models for Mexico show that the average annual surface temperature can experience a wide variety of increases ranging from 0.5 to 5 °C depending on the selected scenario and period and that can reach values above 40 °C, while the percentages of change in rainfall from -20.3% to 13.5% according to scenario and analysis period with decreases of up to -180 mm/year. It is estimated that it is unlikely to limit GHGs and radiative forcing to scenarios SSP1-1.9 and SSP1-2.6, on the other hand it is expected that the actions taken to mitigate GHG emissions allow the worst scenario (SSP5-8.5) not to be reached, based on this it is estimated that the two most likely scenarios are the intermediate scenario SSP2-4.5 and the high scenario SSP3-7.0, which will be described and discussed. For changes in average, maximum and minimum temperatures, annual and monthly precipitation, relative humidity and SPEI, the period 1995-2014 will be taken as a reference and with which the impacts on the health sector will be evaluated.

For the SSP2-4.5 scenario, the average annual temperature for Mexico in the period 2020-2039 is estimated at 22.09±4.13 °C, for 2040-2059 of 22.73±4.13 °C, the period 2060-2069 of 23.23±4.15 °C and at the end of the century (2080-2099) it will reach a value of 23.61±4.18 °C (Table 1). It must be remembered that the values are differentiated according to the region, state, and municipality. In the SSP3-7.0 scenario, the average annual temperature between 2020-

2039 is estimated at 22.02±4.12 °C, between 2040-2059 22.86±4.15 °C, the period 2060-2069 of 23.76±4.20 °C and in 2080-2099 of 24.76±4.21 °C (Table 1 and Figure 2).

However, it must be remembered that health crisis events in people develop with extreme temperatures (maximum and minimum), rather than with averages. Thus, for the SP2-4.5 scenario, the minimum annual temperature for Mexico in the period 2020-2039 is estimated at 14.41±4.06 °C, for 2040-2059 of 15.00±4.08°C, between 2060-2069 of 15.46±4.12°C and at the end of the century (2080-2099) it will reach a value of 15.82±4.13 °C. In the SSP3-7.0 scenario the minimum annual temperature between 2020-2039 is estimated at 14.37±4.05 °C, for 2040-2059 of 15.15±4.10 °C, between 2060-2069 of 16.01±4.14 °C and in 2080-2099 it will reach 16.98±4.15 °C (Table 1).

It is very likely that the maximum temperature is one of the variables that most impacts health. Thus, the maximum annual temperature for the SSP2-4.5 scenario in the period 2020-2039 is estimated at 29.81±4.02 °C, for 2040-2059 of 30.48±4.03°C, the period 2060-2069 of 31.02±4.06°C and at the end of the century (2080-2099) it will reach a value of 31.34±4.07 °C (Table 1). In the SSP3-7.0 scenario the maximum annual temperature between 2020-2039 is estimated at 29.70±4.00 °C, for 2040-2059 of 30.58±4.02 °C, the period 2060-2069 of 31.55±4.08 °C and in 2080-2099 it will reach 32.57±4.11°C (Table 1 and Figure 3).

Mexico's regional relative humidity projections estimate that for the SSP2-4.5 scenario in the period 2020-2039 it is estimated at 57.18±6.50%, while for 2040-2059 of 56.61±6.75%, between 2060-2069 of 56.05±6.86% and at the end of the century (2080-2099) it will reach 55.65±7.03% (Table 1). In the SSP3-7.0 scenario, the relative humidity between 2020-2039 is estimated at 57.39±6.61%, between 2040-2059 of 56.56±6.65%, between 2060-2069 of 55.40±6.97 and in 2080-2099 it will reach 54.66±7.27% (Table 1).

The regional precipitation projections showed negative and positive changes depending on the period analyzed and/or the region of the country. The most important changes are in the North, Central and South of Mexico; With a decrease in rainfall in most of the country. For the SP2-4.5 scenario, the average annual rainfall (mm) in the period 2020-2039 is estimated at 900.03±43.11, for 2040-2059 with a value of 887.34±43.16, between 2060-2069 of 873.13±42.79 and at the end of the century 2080-2099 of 857.83±42.27 (Table 1). In the SSP3-7.0 scenario, the average annual precipitation (mm) in the period 2020-2039 is estimated at 886.88±41.61, for 2040-2059 of 856.44±40.75, between 2060-2069 of 827.52±39.54 and in 2080-2099 it will reach 805.27±39.13 (Table 1 and Figure 4).

The SPEI annual drought index presented for the SP2-4.5 scenario, in the period 2020-2039 value of -0.03±0.02, for 2040-2059 of -0.07±0.02, between 2060-2069 of -0.14±0.05 and between 2080-2099 of -0.17±0.07 (Table 1). In the SSP3-7.0 scenario, the SPEI in the period 2020-2039 is estimated at -0.02±0.01, for 2040-2059 -0.09±0.04, between 2060-2069 of -0.25±0.07 and in 2080-2099 it will reach -0.40±0.13% (Table 1 and Figure 5).

Mexico is one of the regions of the world where rainfall is most likely to decrease under climate change [4]. These reductions in precipitation combined with large increases in temperature imply a large increase in potential evapotranspiration and substantial reduction in water availability and soil moisture, affecting agricultural and livestock productivity that could jeopardize food security, the availability of water for human consumption and with it problems in human health. Thus, in general, it is expected by the end of the century the temperature anomalies will range between 0.6 to 4.5 ° C and that in rainfall is between -45 and -115 mm, decrease de relative humidity by almost 5% and increases in drought as a consequence. Natural climate variability in some cases produces larger changes in annual precipitation than those estimated by climate change. However, if a large negative anomaly in precipitation due to natural variability is combined with negative anomaly due to climate change, then the effect would be magnified and the availability of water for all uses would decrease significantly, leading to lack of hygiene, water for human consumption and food production, which will produce and/or aggravate health problems.

The temporal evolution of the projections indicates that increases in temperatures, decreases in relative humidity and precipitation are more likely to be more important during the second half of the twenty-first century, showing a clear negative trend in any of the CIMP6 scenarios. If we add to this the observations of soil moisture, Index SPEI12, NDVI and drought events (Figure 6) gives us a more robust picture of how temperature and precipitation changes will affect Mexico's water resources agricultural activities, putting food security at risk and affecting human health.

The soil moisture map (mm) allows us to show that the North, West and Bajío areas have the lowest values of soil moisture with values below 0.1, which will be intensified with higher temperatures that will cause greater evaporation and with less rainfall that will not allow the ecosystem to recover and maintain the conditions of equilibrium; which will impact water stress on vegetation, crops, water supply, food production and health [17]. The South, Gulf and Southeast areas, although they have a higher level of soil moisture (between 0.2 and 0.4 mm), will also be affected as a result of climate change (Figure 6a). SPEI is a standardized version of precipitation anomalies and has been used to characterize the severity of meteorological drought [18]. SPEI12 allows to evidence the effects of persistent precipitation anomalies and estimate the potential trend to more meteorological droughts. The map of SPEI12 shows prolonged drought such as those that occurred in the decades of 1910, 1930, 1950, 1970 and those of the late 1990s to date throughout the country, with more intensity in the North (Figure 6b). The magnitude of SPEI12 during the twentieth century ranged from -1 to −2 in episodes of prolonged drought, which corresponds to extremely dry conditions. The corresponding projections of multi-model precipitation on a regional scale for 2000−2099 do not include the magnitude of observed natural variability. However, a more definite trend towards negative SPEI12 values is observed in the SSP3-7.0 scenario than in the SSP2-4.5 scenario, with average values of around -1, conditions considered as semi-permanent moderate meteorological drought.

Table 1. Average, minimum, maximum temperatures, relative humidity, precipitation, and SPEI drought index for Mexico according to the different scenarios of the IPCC (2021) SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5 during this century, obtained from regional models (Own elaboration with data from CCKP, 2022).

Average temperatures in °C				
	2020-2039	2040-2059	2060-2079	2080-2089
SSP1-1.9	21.95±4.18	22.08±4.17	21.97±4.18	21.88±4.18
SSP1-2.6	22.09±4.14	22.45±4.14	22.58±4.15	22.51±4.16
SSP2-4.5	22.09±4.13	22.73±4.13	23.23±4.15	23.61±4.18
SSP3-7.0	22.02±4.12	22.86±4.15	23.76±4.20	24.76±4.21
SSP5-8.5	22.20±4.12	23.20±4.13	24.40±4.14	25.80±4.14
Minimum temperatures in °C				
	2020-2039	2040-2059	2060-2079	2080-2089
SSP1-1.9	14.41±4.13	14.54±4.14	14.47±4.11	14.34±4.13
SSP1-2.6	14.36±4.07	14.69±4.06	14.78±4.07	14.73±4.07
SSP2-4.5	14.41±4.06	15.00±4.08	15.46±4.12	15.82±4.13
SSP3-7.0	14.37±4.05	15.15±4.10	01.01.00±.14	16.98±4.15
SSP5-8.5	14.56±4.06	15.50±4.09	16.69±4.12	18.03±4.18
Maximum temperatures in °C				
	2020-2039	2040-2059	2060-2079	2080-2089
SSP1-1.9	29.61±4.05	29.72±4.07	29.60±4.09	29.95±4.09
SSP1-2.6	29.78±4.02	30.18±4.04	30.31±4.05	30.25±4.08
SSP2-4.5	29.81±4.02	30.48±4.03	31.02±4.06	31.34±4.07
SSP3-7.0	29.70±4.00	30.58±4.02	31.55±4.08	32.57±4.11
SSP5-8.5	29.84±4.02	30.89±4.02	32.12±4.03	33.57±4.13
Relative humidity in %				
	2020-2039	2040-2059	2060-2079	2080-2089
SSP1-1.9	57.32±6.91	57.96±6.94	57.23±6.85	57.66±6.64
SSP1-2.6	56.92±6.60	56.93±6.49	56.34±6.59	56.64±6.60
SSP2-4.5	57.18±6.50	56.61±6.75	56.05±6.86	55.65±7.03
SSP3-7.0	57.39±6.61	56.56±6.65	55.40±6.97	54.66±7.27
SSP5-8.5	57.28±6.63	56.18±6.82	55.20±7.12	53.59±7.48
Precipitation in mm				
	2020-2039	2040-2059	2060-2079	2080-2089
SSP1-1.9	917.43±45.89	929.51±46.17	925.79±45.30	917.49±45.24
SSP1-2.6	911.97±43.62	901.93±42.82	890.75±41.93	899.51±42.62
SSP2-4.5	900.03±43.11	887.34±43.16	873.13±42.79	857.83±42.27
SSP3-7.0	886.88±41.61	856.44±40.75	827.52±39.54	805.27±39.13
SSP5-8.5	877.25±42.28	858.70±41.36	831.01±40.81	786.00±40.20
SPEI Annual Drought Index				
	2020-2039	2040-2059	2060-2079	2080-2089
SSP1-1.9	-0.06±0.03	-0.05±0.06	-0.06±0.05	-0.05±0.04
SSP1-2.6	-0.02±0.01	-0.03±0.01	-0.05±0.02	-0.05±0.02
SSP2-4.5	-0.03±0.02	-0.07±0.02	-0.14±0.05	-0.17±0.07
SSP3-7.0	-0.02±0.01	-0.09±0.04	-0.25±0.07	-0.40±0.13
SSP5-8.5	-0.04±0.03	-0.22±0.13	-0.45±0.11	-0.82±0.14

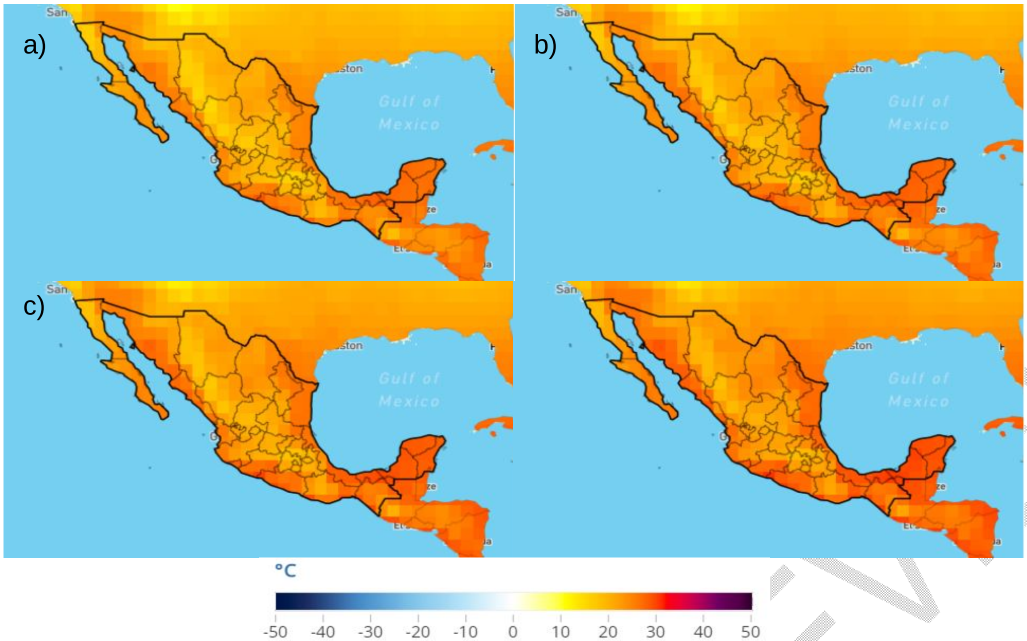

Fig. 2. Average (Annual) temperature projected for Mexico under scenario SSP3-7.0 a) 2020-2039; (b) 2040-2059; (c) 2060-2079 and (d) 2080-2099 (CCKP, 2022).

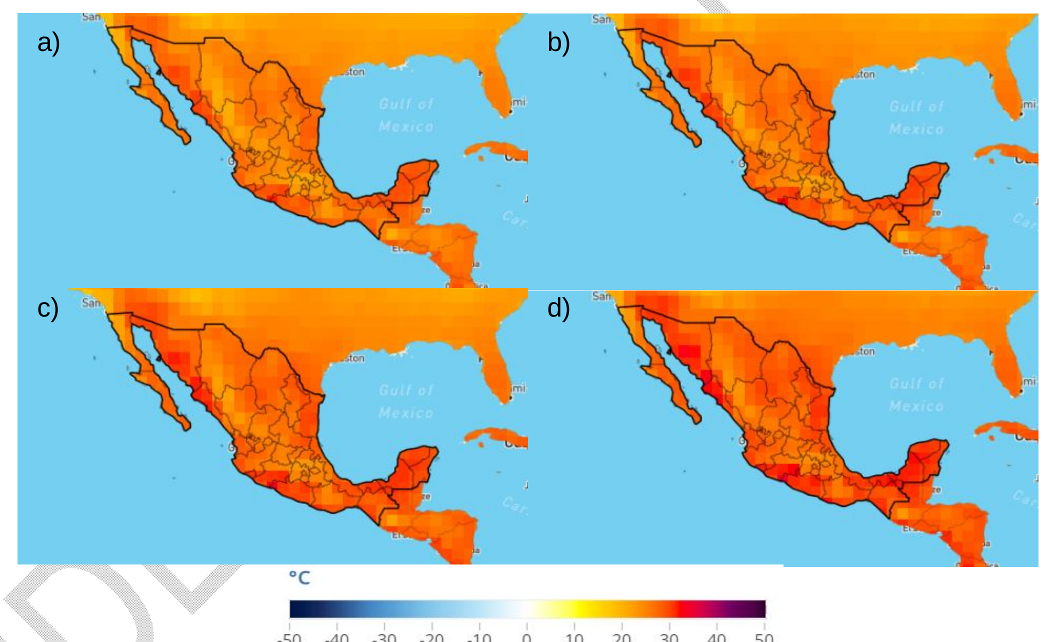

Figure 3. Maximum temperature (Annual) projected for Mexico under scenario SSP3-7.0 a) 2020-2039; (b) 2040-2059; (c) 2060-2079 and (d) 2080-2099 (CCKP, 2022).

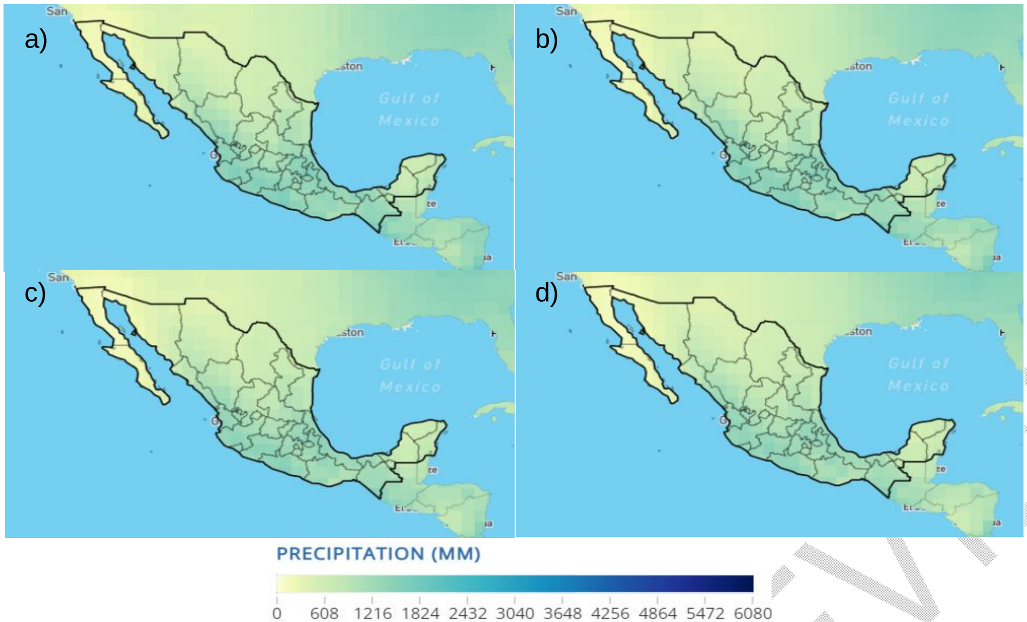

Fig. 4. Projected precipitation (Annual) for Mexico under scenario SSP3-7.0 a) 2020-2039; (b) 2040-2059; (c) 2060-2079 and (d) 2080-2099 (CCKP, 2022).

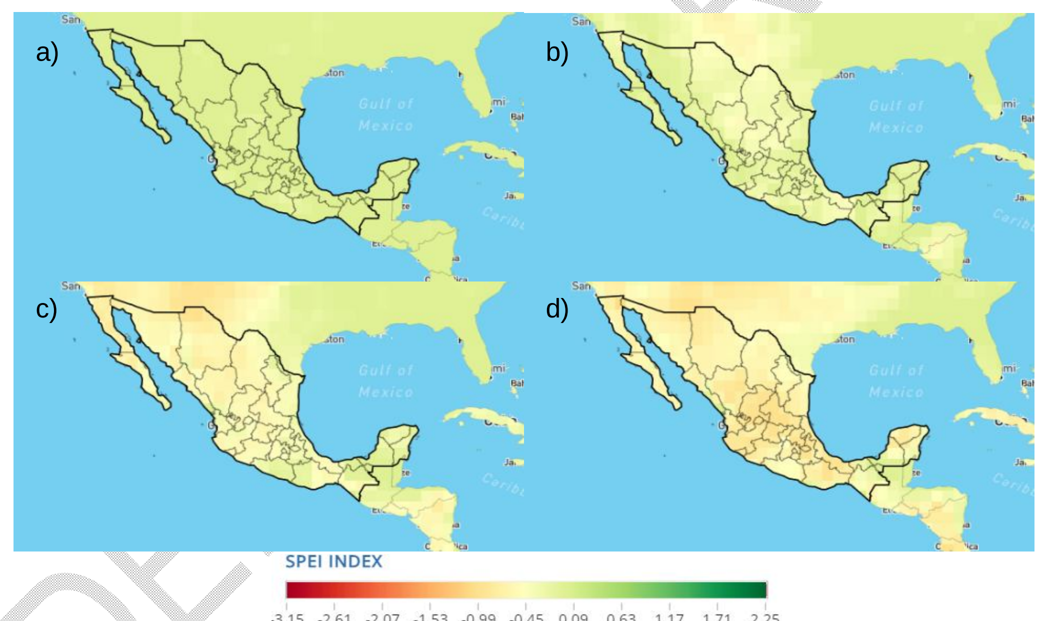

Fig. 5. Annual SPEI drought index of the projected climatology for Mexico under scenario SSP3-7.0 a) 2020-2039; (b) 2040-2059; (c) 2060-2079 and (d) 2080-2099 (CCKP, 2022).

The NDVI (Figure 6c) is closely related to soil temperature and moisture [19]. Thus, the NDVI changes over Mexico are related to reductions in rainfall and increased temperatures. By the second half of the 21st century projected patterns of severe soil moisture deficit and water stress with terrible consequences. NDVI values indicate sparse vegetation. Projected changes in soil moisture and NDVI in SSP scenarios resemble observed changes under intense ENSO event conditions (1982-1983, 1986-1993, 1997-1998, 2014-2016). Most of the affected regions are semi-arid areas. Very low frequency climate variability over Mexico with temperature anomalies of 5 °C and decreased rainfall resulted in an increase in forest fires without considering the effect of climate change. If climate change anomalies are added to these conditions, it is possible that fires in forests and jungles will increase during the present century, with the effects on health.

Regional climate change scenarios suggest that by the end of the century, water availability in northern Mexico may be reduced by up to 30%, a consequence of reduced rainfall and temperature increase. High anomalous temperatures in northern Mexico persisted into the summers of 1998-2002 (around +2 °C) with below-normal rainfall (-20 to -30%), leading to prolonged drought. Such climatic anomalies resulted in a severe deficit of soil moisture and water stress that increased the potential for wildfires. The spring of 1998 was one of the seasons with the highest number of forest fires in recent decades, hydrological stress, agricultural slash, and burn [20]. Vulnerability in northern Mexico has not been reduced [21] and the risk is still present [22] and will be complicated by climate change.

The drought map (Figure 6d) shows that practically the entire country has suffered from moderate droughts (Center and South of the country) to extremely strong (North of the country). Under the climate change scenarios SSP2-4.5 and SSP3-7.0 with conditions of strong increase in temperatures, decrease in humidity and rainfall, the drought scenario in Mexico will last and worsen until the end of the century, with implications in the water and agricultural sectors and will put food security and health at risk.

Impacts of climate change on water resources

On a global scale, it is expected that the effects of climate change on water and agricultural resources will be extensive, but differentiated from one region to another, according to latitude, altitude, biomes, orographic conditions, hydrography, among others. In some regions of the planet, symptoms of impact on water resources and health are already registered.

With climatology, an increase in surface temperature in Mexico of approximately 1.8 °C was already evidenced by 2020 compared to 1900, above the global values of 1.09 for 2020 with respect to 1850 [6].

Regional CIMP6 models for Mexico show that in most of the Mexican territory heat waves are more frequent and intense, while extreme cold events have decreased in frequency and intensity. This has led to very warm summers and less harsh winters, which is consistent with the global projections of the AOGCM [6].

In the case of Mexico, the projected regional scenarios show that Mexico's surface temperature will continue to increase from 2020 to 2080-2099 in all GHG emissions scenarios considered, exceeding the threshold of 2 °C increase and reaching values of up to almost 5 °C in average, maximum and minimum temperatures. This coincides with the projection of OACG models with higher increments to 1.5 °C and 2 °C during the twenty-first century [6]. The projections show that Mexico will present the following increases with respect to the period of 1994-2014: between 2081-2099 for the intermediate scenario SSP2-4.5, from 1.78 to 2.58 °C and for the high scenario SSP3-7.0 it will reach 2.75 to 3.84 °C. In the first case below the estimate by the IPCC (2.1 to 3.5 °C) and in the second case within the range projected by the IPCC (2.8 °C to 4.6 °C) globally [6].

In Mexico, the projected regional scenarios will reach temperature levels higher than the global ones (1.8°C), which is very likely to increase both in frequency and intensity of hot extremes (heat waves, intense rainfall, meteorological, agricultural, and ecological droughts as never before observed), which coincides with what is estimated in the VI IPCC report [6].

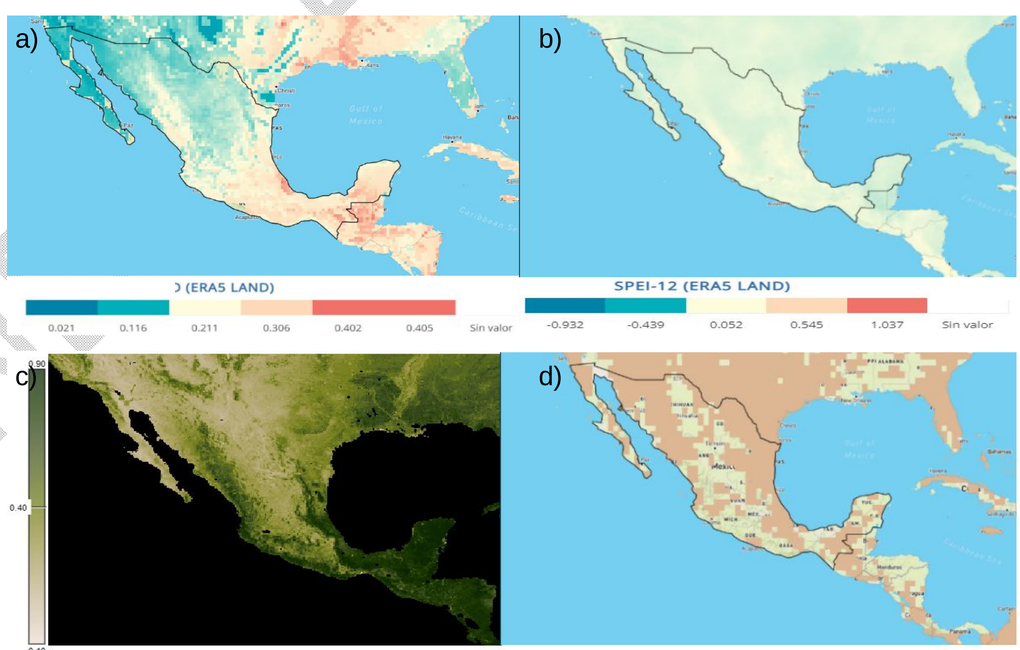

Fig. 6. (a) Soil moisture (mm) and (b) SPEI12, c) changes in the Normalized Difference Vegetation Index (NDVI) and d) Drought events in the SSP2-4.5 scenario for the second half of the 21st century. (CCPK and NASA 2022).

Global assessments project that some mid-latitude and semi-arid regions will see the largest increase in temperature on the hottest days, about 1.5 to 2 times the rate of global warming [6]. Mexico is located within these regions so regional projections coincide with the estimates with global projections with temperature increase on hot days in the global ranges of 1.5 to 2 times the rate of warming.

Global phenomena projected by regional models for Mexico where it is estimated that in the present century the frequency of extreme events (heat waves, recurrent droughts, forest fires and floods) will increase as a result of the increase in temperatures and decrease in relative humidity and rainfall, in agreement with the global estimates of the AOGCM [6].

In terms of precipitation, the IPCC mentions that heavy rainfall events are very likely to intensify and become more frequent in most regions with additional global warming. On a global scale, global warming extreme daily precipitation events are projected to intensify by about 7% per 1°C [6]. In Mexico, only slight increases in rainfall will occur in the first period (2020-2039) and in the very low and low scenarios. In the rest of the scenarios the tendency will be to decrease precipitation. However, in all cases the intensity of the rains will increase and there relative humidity will decrease its percentages for all of Mexico.

Continued global warming is also expected to further intensify the water cycle, including water variability, monsoon precipitation and the severity of wet and dry events [6]. In Mexico, the initial period (2020-2039) will present increases in the amount of precipitation, but in the subsequent periods (2040-2059, 2060-2079 and 2080-2099) there will be a decrease in wet events and a greater presence of dry ones, intensifying drought to prolonged drought.

There is strong evidence that the global water cycle will continue to intensify as global temperatures rise and precipitation and surface water flows become more variable within seasons and from year to year. On land, the global annual average precipitation is projected to increase between 0–5% in the very low scenario (SSP1-1.9), between 1.5–8% for the scenario (SSP2-4.5) and 1–13% in the very high GHG scenario (SSP5–8.5) for 2081–2100 relative to 1995–2014. Precipitation is projected to increase in high latitudes, equatorial Pacific, and monsoon regions, but decreases in parts of the subtropics and limited areas in the tropics in SSP2-4.5, SSP3-7.0 and SSP5-8.5 [6]. The regional projections for Mexico coincide with the global forecasts of tropical areas with decreased rainfall in the scenarios SSP2-4.5 (-5.81±7.59%), SSP3-7.0 (-10.59±12.66) and SSP5-8.5 (-12.80±16.15) in the period 2080-2099.

It is estimated that a warmer climate will intensify very wet and very dry weather, events, and weather seasons, with implications for floods or droughts, but the location and frequency of these events will depend on changes in regional atmospheric circulation. It is very likely that the variability of rainfall associated with ENSO will be amplified by the second half of the century in the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios [6]. The regional projections for Mexico of soil moisture decline, the SPEI 12 index, NVDI and the large periods of drought of recent decades confirm for Mexico the global estimates of intensification of very dry weather and prolonged droughts.

The monsoon season is projected to have a late start in North America [6]. Regional projections estimate that North America's monsoon will be increasingly delayed as the century progresses, along with decreased precipitation, will cause storage problems in the country's water bodies.

Increases ≥2°C of global warming, the level of confidence and magnitude of change in droughts, and intense and medium rainfall are estimated to increase. Se projects for North-America an increase in meteorological, hydrological, and agricultural droughts [6]. This has already manifested itself in Mexico during the first two decades of this century and is projected to intensify at the end of the century.

Many regions are predicted to experience an increase in the likelihood of compound events such as more frequent heat waves and concurrent droughts, even in crop-producing areas, becoming more frequent at 2°C compared to warming of 1.5°C [6]. The estimates for the end of the century in Mexico under the most likely scenarios will be above 2 °C (0.8-3.5 °C) which could mean effects from events composed of heat waves; Decreased humidity, precipitation, water availability and presence of droughts.

In general, in mid-latitudes and subtropical zones (location of Mexico), significant decreases in precipitation and runoff are expected, which will cause an increase in scarcity conditions and greater pressure on diversified water resources in different regions. In various regions of the world and in Mexico, there are already conditions of scarcity of water resources and agricultural products; even without climate change, due to population growth, urban concentration, pollution of water bodies and overexploitation of water resources, particularly underground resources, coupled with a scarce water culture. To this scenario must be added the effects of climate change, which in Mexico will be a reduction in the natural availability of water as a result of the increase in temperature and decrease in rainfall, which together poses very great challenges for the management and sustainable use of water, with decreases in agricultural or livestock productivity. which will jeopardize food production, the country's food security and health.

According to the IPCC (2007), in many regions current water management practices are inadequate or insufficient to meet the challenges of climate change. Mexico is one of the countries in which the public management policies implemented so far will not be sufficient to face the impacts of climate change [4].

On the other hand, a warmer climate will mean more intense precipitation events, even in places where the average annual precipitation is likely to be lower. What is already happening and will continue to happen in southern and southeastern Mexico. The average annual precipitation may even decrease, but heavier rains will be recorded, which will make it more difficult to control the flows through the current channels. These extreme events will be among the most difficult to forecast in future climate change scenarios, as they have an eminently local character. It is expected that the impacts of global warming on runoff will be detected first in the occurrence of extreme events than in availability, which in itself has important natural variations.

In the case of Mexico, this effect of climate change will increase vulnerability in basins in southern and southeastern Mexico where flooding problems are already recorded [23], with concomitant health problems. The existence of heavier rainfall is compatible with the forecast of lower annual runoff. On the other hand, the increase in the occurrence of droughts in the north of the Mexican territory is evident, which is consistent with the predictions of decreased precipitation and runoff and is expected to occur more frequently and intensely. If adaptation measures are not adopted, the availability of water resources in quantity and quality could be at great risk and, as a consequence, agricultural or livestock productivity, food security and the health of the population of Mexico.

Impacts of climate change on the health sector in Mexico

The Health Sector in Mexico was created in 1943 and is a conjunction of public and private institutions that do not guarantee access to health and quality services for all. The Health System in Mexico comprises two sectors, the public and the private. Within the public sector are social security institutions: Mexican Social Security Institute (IMSS), Institute of Security and Social Services of State Workers (ISSSTE), Petróleos Mexicanos (PEMEX), Ministry of Defense (SEDENA), Ministry of the Navy (SEMAR) among others and institutions and programs that serve the population without social security: Health Secretary (SSa), State Health Services (SESA), IMSS-Oportunidades Program (IMSS-O), Popular Seguro (SP)]. The private sector comprises: insurance companies and service providers working in pharmacies, clinics, clinics and private hospitals, including alternative medicine service providers.

According to the World Health Organization (WHO) "Health systems must provide the entire population with access to necessary health services, including prevention, promotion, treatment and quality rehabilitation and ensure that the use of these services does not expose the user to financial difficulties." It further states that "universal access to health and universal health coverage imply that all individuals and communities have access, without discrimination, to comprehensive, adequate, timely, quality health services, nationally determined, according to need, as well as to quality, safe, effective and affordable medicines, while ensuring that the use of these services does not expose users to financial difficulties, particularly vulnerable groups".

Health in Mexico has fewer resources than other Organization for Economic Cooperation and Development (OECD) countries. Currently, Mexico spends 6.2% (2020) of GDP on health (Fig 7), less than the OECD average of 8.9%, equivalent to $1230 dollars per capita per year (PPP) (OECD average is $4000 PPP dollars in 2020) (Figure 8). Out-of-pocket spending in Mexico constitutes 45% of health system income and 4.0% of household spending. Both figures are among the highest in the OECD [24].

In 2000, the total population of Mexico was 97,873,442 inhabitants, and in 2021 it had risen to 126,705,138, representing an increase of 29.5% [24]. As for the demographic profile of the country, in 2021 the population over 65 years of age represented 8.1% of the total, implying an increase of 3.1 percentage point compared to 2000. Likewise, in 2021 a ratio of 104.8 women for every 100 men was reached and 32.6 older people (65 years or older) for every 100 children under 15 years of age, as observed in the distribution by age group and sex of the country's population pyramids (Figure 9). Life expectancy at birth by 2021 was 75.2 years. The percentage of the population below the poverty line was 43.9% in 2020, according to the national line, which represents a decrease compared to 2008, when it was at 44.4%. With regard to poverty defined as a percentage of the population with an income of less than US$ 1.90 per day, in 2020 3.1% of the population was in this situation, a figure higher than the regional average of 3% [25].

During the period 2000-2021, the country increased its score on the Human Development Index, which showed an increase of 6.9% (out of a score of 0.709 to one of 0.758), while in the same period the index increased 15% internationally and 11% in Latin America. In 2019, public spending on health accounted for 2.7% of gross domestic product (GDP) and 10.3% of total public spending, while out-of-pocket spending on health implied 42.1% of total health expenditure [25].

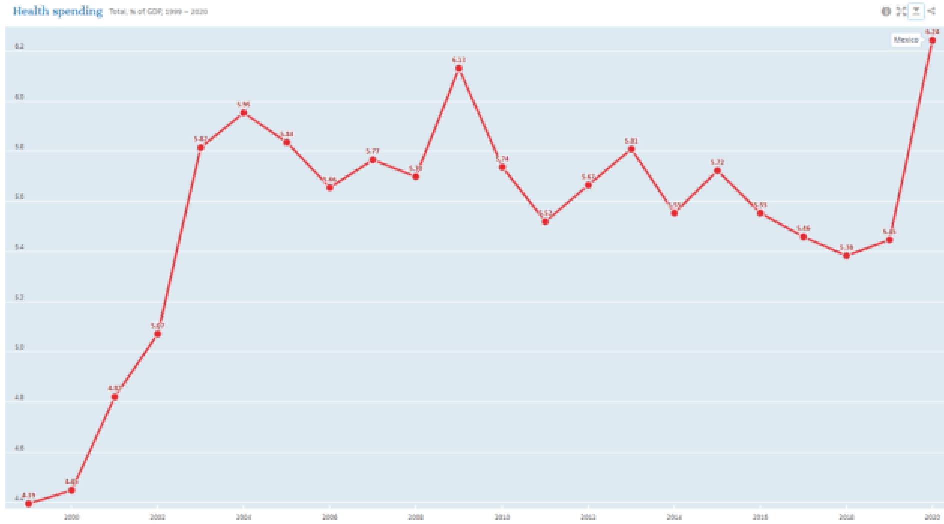

Figure 7 Health expenditure. Total, % of GDP, 1999 – 2020. OECD [24]

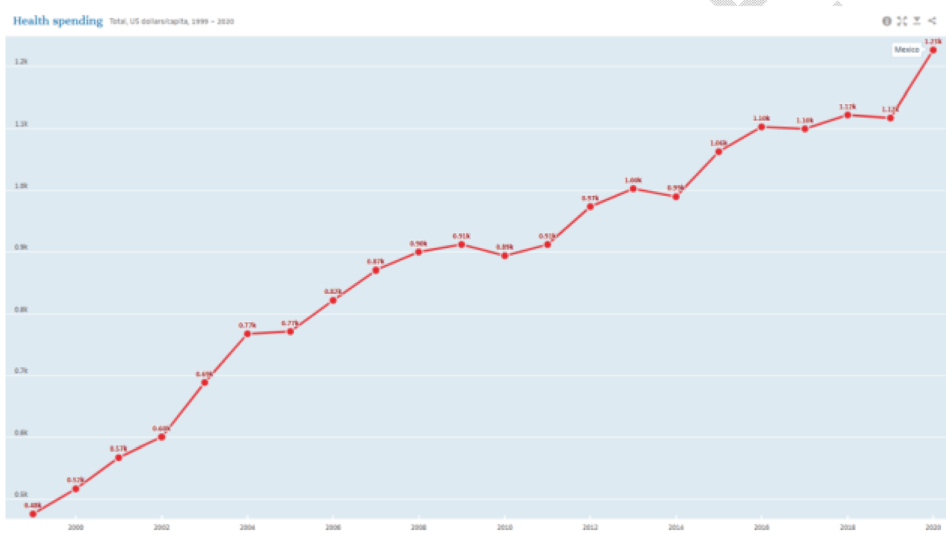

Figure 8 Health expenditure. Total, U.S. dollars/capita, 1999 – 2020. OECD [24]

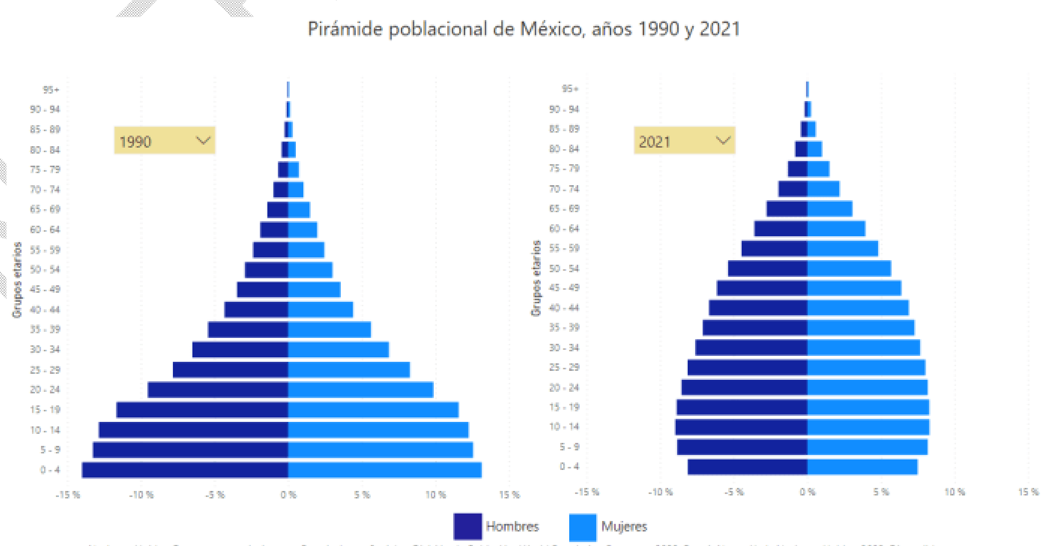

Figure. 9 Population pyramids of Mexico for 1990 and 2021 [25]

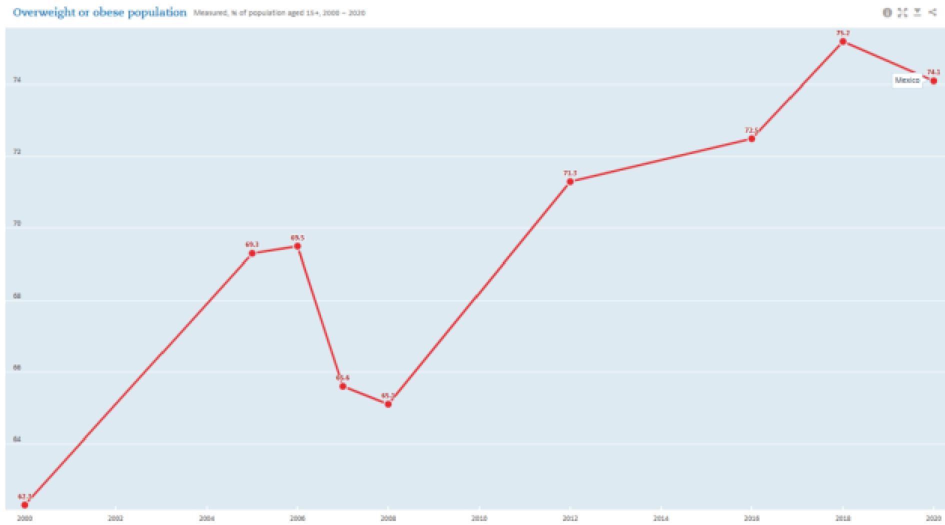

Fig. 10 Population with obesity or overweight. Percentage of population +15 years, 2000-2020. OECD [24]

In Mexico, in relation to overweight and obesity in people over 15 years of age, the prevalence amounted to 72.5% for 2016, 75.2% for 2018 and 74.1% in 2020 (Figure 10)[24]. As for high blood pressure, a prevalence of 19.7% was reported in 2015. of people aged 18 and older with high blood pressure, representing a decrease of 4.1% compared to 2000 (23.8%). On the other hand, the prevalence of diabetes mellitus increased by 9.5% in 2000 to 11.2% in 2014 [25].

Mortality

In 2019, the adjusted rate of potentially avoidable premature mortality in Mexico was 254.5 deaths per 100,000 inhabitants (inhab), which is equivalent to a decrease of 9.4% compared to the rate of 280.9 registered in 2000. In this sense, the country presented in 2019 a rate of 12.3% higher than that reported for the Region of the Americas. Of the potentially preventable premature deaths, the rate for treatable causes was 117.4 per 100,000 inhabitants, compared to the regional average of 89.6. The age-adjusted overall mortality rate in 2019 was 5.8 per 1000 inhabitants, which represents a decrease of 7.6% compared to 2000 (6.2 deaths per 1000 inhabitants) [24-25].

When categorizing deaths into three main groups, it is observed that in 2019 the age-adjusted mortality rate for communicable diseases was 52.4 per 100,000 inhabitants (62.4 per 100,000 in men and 43.7 per 100 000 in women), while for noncommunicable diseases it amounted to 468.7 per 100,000 inhabitants (544.7 per 100,000 in men and 404.6 per 100,000 in women). The rate for external causes was 58.8 per 100,000 inhabitants (99.3 per 100,000 in men and 21.3 per 100,000 in women), in which case land transport accidents stand out (12.9 per 100,000 inhabitants), homicides (25.3 per 100,000 inhabitants) and suicides (5.3 per 100,000 inhabitants). In 2000, the percentage distribution of cases was 70.2% for noncommunicable diseases, 17.9% for transmissible and 11.9% for external causes, while for 2019 the percentages were 80.4%, 9.1%, and 10.5%, respectively [25].

Regarding the increase in deaths, this has been constant between 1998 and 2019 (from 400 000 to 700 000 deaths), and increased dramatically in 2019 and 2020 (in just two years ago from 700 000 to 1 150 000) due to the appearance of the COVID-19 pandemic (Figure 11) [24].

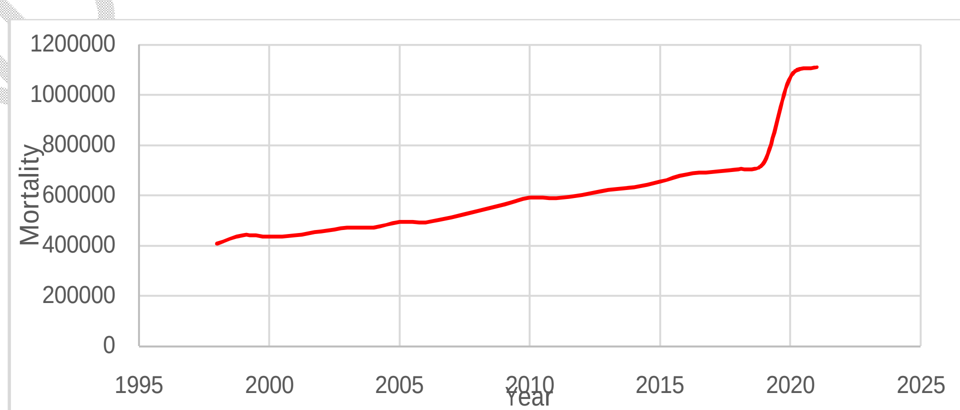

Fig. 11 Mortality in Mexico between 1995-2020. Data from the Information System of the Ministry of Health.

Cancer mortality according to tumoral site during 2019, the male population presented an adjusted mortality rate from prostate cancer of 14.1 per 100,000; lung, 8.5 per 100,000, and colon and rectum, 6.6 per 100,000. In the case of women, the values were 11.2 per 100,000 for breast cancer; 4.3 per 100,000 for lung cancer, and 4.9 per 100,000 for colon and rectal cancer [25].

In the case of diseases caused by zoonoses, during 2020, there were a total of 1,510,795 cases of COVID-19 in Mexico, representing 11,928.8 per million inhabitants. In 2021, the identified cases amounted to 2,536,807, equivalent to 20,016.5 per million inhabitants. With regard to deaths directly caused by COVID-19, in 2020 there were 199,429 deaths of people diagnosed with COVID-19, that is, 1,156 per million inhabitants, while in 2021 238,070 were reported, representing 1,846 deaths per million inhabitants. In the Region of the Americas, Mexico ranked 2nd in terms of the number of deaths from COVID-19 in 2020, and for 2021 it ranked 17th, with a cumulative figure for both years of 3002 deaths per million inhabitants. According to WHO estimates, the total number of excess deaths in 2020 was 314,596 cases, or 244 per 100,000 inhabitants. For 2021, 311,327 deaths were estimated, representing an excess mortality of 239 per 100,000 inhabitants. As of December 31, 2021, at least one dose of COVID-19 vaccine had been given to 66.5% of the country's inhabitants. As of July 2, 2022, 61% of the population had the complete vaccination schedule. The vaccination campaign began on December 20, 2020 and 7 types of vaccines have been used [25].

In the case of vector-borne diseases, there are only reliable records of dengue that presented 36,742 cases in 2021 [25].

Figure 12 shows the main causes of death in Mexico during the last 20 years, where the first places are occupied by some diseases associated with climate change such as heart disease, diabetes mellitus and malignant tumors, cerebrovascular diseases, pneumonia-influenza, chronic lung diseases, bronchitis, emphysema and asthma, intestinal infectious diseases, gastric and duodenal ulcers, malnutrition, anemia, suicides among others [24-25].

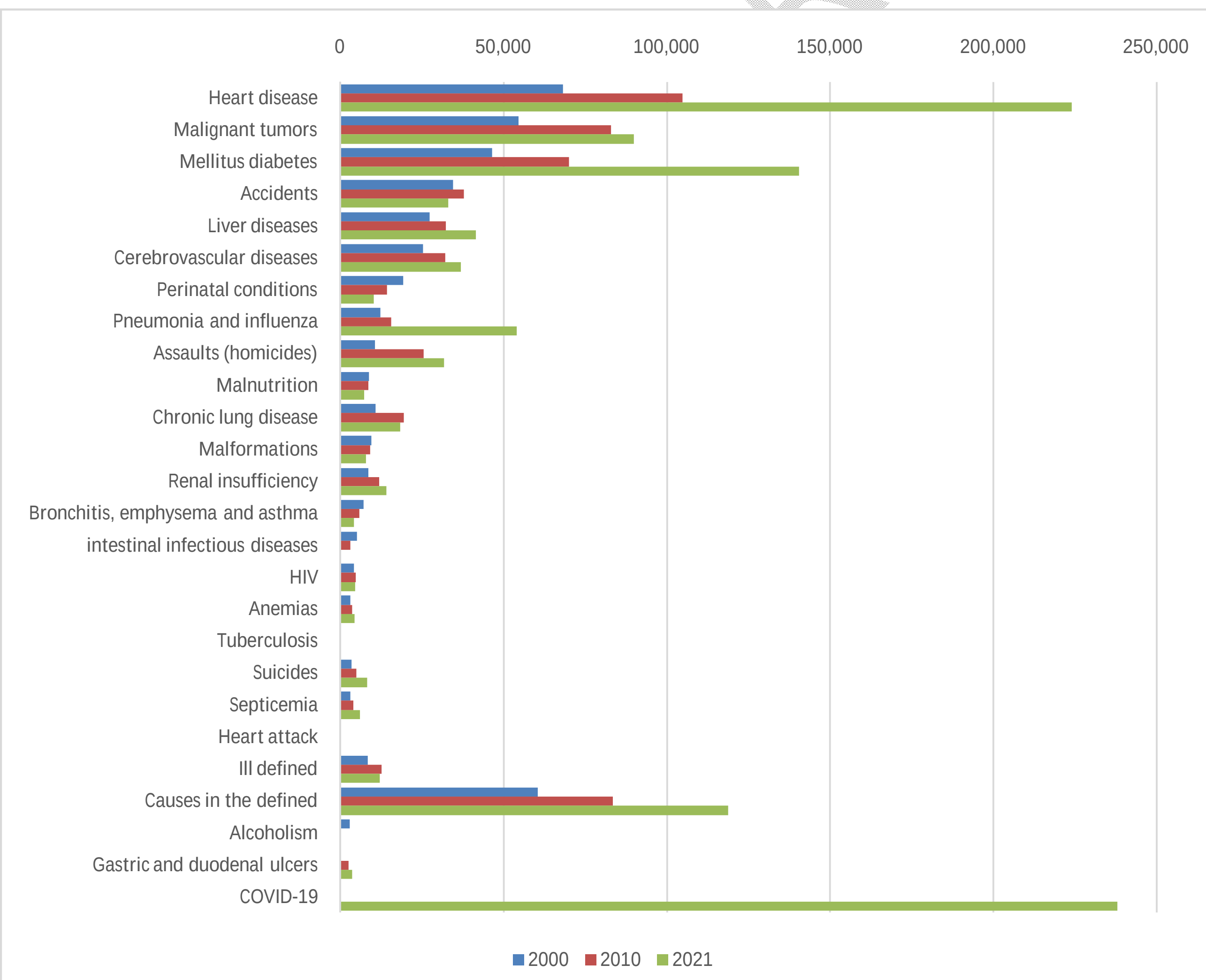

Fig. 12 Main causes of Mortality in Mexico in 2000, 2010 and 2021. Data from the Information System of the Ministry of Health.

If currently the population in Mexico is 128 million (2020), making a simple exercise of population growth to 2050 of 25% (160 million) and to 2100 of 20% (153 million) (Figure 13). Under this scenario, both 2050 and 2100 would have a population of more than 50 million people over 60 years of age with the respective increase in expenses in the conservation of their health. Estimating that in the same proportion health expenditures in Mexico would grow without reducing poverty, nor significantly increasing total and per capita GDP, it would be necessary to triple 6.2% of GDP (2020) to health to more than 18% by 2100, and increase spending from $1230 per capita per year (2020) to $3800 dollars in 2100, which would be unfeasible for the economy. Likewise, out-of-pocket spending in Mexico would constitute at least 65% of health system income and more than 50% of household spending.

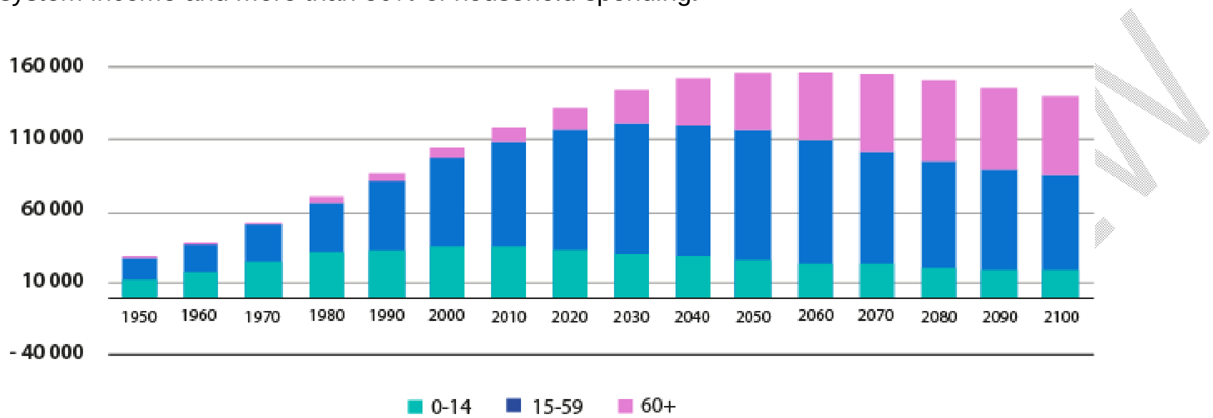

Figure 13 Total population (thousands) and projected age groups for Mexico during the twenty-first century. Source: World Population Survey Data 2012, UN.

Since the regional models for Mexico show that temperature increases ranging from 0.5 to 5 °C, and % precipitation change will range from -20.3% to 13.5% depending on scenario and period of analysis. The low soil moisture (mm), the negative changes of NDVI and SPEI12 show that the whole country will present reductions in precipitation and temperature increase, flooding of lands emerged by sea level rise, disappearance of agricultural land and biodiversity, along with a large number of extreme hot events such as heat waves, intense rainfall, meteorological, agricultural and ecological droughts, decrease in wet events and greater presence of dry periods, intensifying moderate drought to prolonged drought, storage in water bodies and moving from meteorological droughts to hydrological and agricultural droughts and a greater number of forest fires, decrease in food productivity, malnutrition and scenarios of greater vulnerability to the appearance and exacerbation of diseases typical of the Mexican (chronic-degenerative diseases, obesity, Diabetes mellitus, among others) and greater vulnerability to diseases produced by climate change such as heat stress, heat islands, respiratory diseases, vector-borne diseases and contaminated water, water and food shortages; mental illnesses, environmental refugees among others.

According to the 6th IPCC report, climate change has negatively affected the physical and mental health of people around the world and in the regions assessed. The health impacts of climate change are mediated by natural and human systems, including economic and social conditions. In all regions, extreme heat events have caused human mortality and morbidity. The incidence of climate-related foodborne and waterborne illness has increased. The incidence of vector-borne diseases has increased due to the expansion of the range and/or increased reproduction of vectors. Animal and human diseases, including zoonoses, are emerging in new areas. The risks of waterborne and foodborne diseases have increased regionally due to climate-sensitive aquatic pathogens, and toxic substances from harmful cyanobacteria. Although diarrheal diseases have declined globally, higher temperatures, increased rainfall and flooding have increased the occurrence of diarrheal diseases, including cholera and other gastrointestinal infections. Mental health challenges are associated with rising temperatures, trauma from extreme weather and climate events, and loss of livelihoods and culture. Increased exposure to wildfire smoke, atmospheric dust, and aeroallergens is associated with climate-sensitive cardiovascular and respiratory distress. Health services have been disrupted by extreme events such as flooding [6]. In Mexico all these avalanche disorders are already present and have increased during the last 20 years (Figure 12) such is the case of human mortality and morbidity due to increased diseases due to contaminated food, vectors such as dengue, zika and Chikungunya; transmitted by water such as cholera, red tide, and mental illnesses such as anxiety, depression (product of trauma from extreme events and heat), respiratory, cardiovascular and allergic diseases resulting from fires and air pollution and health services have been interrupted and in some cases disappeared by extreme flooding events in southeastern Mexico

The IPCC mentions that climate change is contributing to humanitarian crises in which climate hazards interact with high vulnerability. Extreme weather and climate events are increasingly driving displacement in all regions. Acute food insecurity and malnutrition related to floods and drought have increased. While non-climatic factors are the dominant drivers of existing violent intra-State conflicts, in some regions assessed, extreme weather and climate events have had an impact. Through displacement and involuntary migration due to extreme weather and climate events, climate change has generated and perpetuated vulnerability [6]. Phenomena that in Mexico are already occurring where indigenous communities leave their places of origin and migrate to large cities in search of opportunities, facing these problems, seeing their health compromised by traumas and loss of life in extreme weather events, malnutrition and anemia due to food insecurity, malnutrition and stress, anxiety and depression due to losses in extreme events or violent conflicts.

Regions and people with development constraints are highly vulnerable to climate hazards. Vulnerability is greatest in places with poverty, governance challenges and limited access to basic services and resources, violent conflict, and high levels of climate-sensitive livelihoods (smallholders, pastoralists, fishing communities). Between 2010 and 2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions of very low vulnerability. Vulnerability at different spatial levels is exacerbated by inequity and marginalization linked to gender, ethnicity, low income, or combinations thereof, especially for indigenous peoples and local communities [6]. Typical examples are the indigenous communities throughout Mexico who are the ones who suffer from this high vulnerability and that causes damage to their own health and that of the societies where they develop.

Climate change puts increasing pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition. Increases in the frequency, intensity and severity of droughts, floods and heat waves, and continued sea level rise will increase food security risks in moderately to high-to-moderate vulnerable regions between 1.5-2°C global warming level, with zero or low levels of adaptation. At a level of global warming of 2°C or more in the medium term, food security risks due to climate change will be more severe, leading to malnutrition and micronutrient deficiencies. Global warming will weaken soil health and pollination, increase pest and disease pressure, and reduce marine animal biomass, undermining food productivity in many regions. At global warming of 3°C or more in the long term, areas exposed to climate-related hazards will expand substantially, exacerbating regional disparity in food security risks [6]. Mexico is already experiencing these ravages where in many regions the health of the population is being compromised by food insecurity, malnutrition and diseases that result from it, along with the rest of diseases associated with climate change.

Climate change and related extreme events will significantly increase short- and long-term ill health and premature deaths. Globally, population exposure to heat waves will continue to increase with additional warming, with geographic differences in heat-related mortality without additional adaptation. The risks of food-borne diseases, water and climate-sensitive vectors are projected to increase at all levels of warming without additional adaptation. In particular, the risk of dengue will increase with longer seasons and wider geographical distribution, which could put millions of people at risk by the end of the century. Mental health cases, including anxiety and stress, are expected to increase under increased global warming, particularly for children, adolescents, the elderly, and those with health conditions [6]. In Mexico, the increase in Dengue, Zika, Chikungunya, Cholera, gastrointestinal problems, anxiety, depression and stress is already manifested; and these are expected to increase significantly with the increase in temperature, decrease in rainfall and the increasingly recurrent presence of extreme weather events.

Climate change risks to cities, settlements and key infrastructure will increase rapidly in the medium and long term with further global warming, especially in places already exposed to high temperatures, along coasts or with high vulnerabilities. The population potentially exposed to coastal flooding in 100 years is projected to increase by approximately 20 % if mean sea level rises by 0.15 m compared to 2020; the exposed population doubles with a 0.75 m rise in sea level and triples to 1.4 m with no population change and further adaptation. The costs of maintaining and rebuilding infrastructure will increase with the level of global warming, the associated functional disruptions are projected to be substantial, particularly for cities, settlements, and infrastructure located in cold regions and coasts [6]. In the case of Mexico, the most important risks occur on the coasts of the Gulf of Mexico and the Caribbean Sea where the greatest increases in sea level are expected, the cold regions in Mexico will initially be favored, but perhaps by the end of the century they will begin to have health problems.

In the medium and long term, displacement will increase with intensified heavy rainfall and related flooding, tropical cyclones, drought, and sea-level rise. At progressive levels of warming, there would be an involuntary migration from regions with high exposure and low adaptive capacity. At higher levels of global warming, the impacts of extreme weather and climate events, particularly drought, by increasing vulnerability, will increasingly affect violent intra-state conflicts with consequent mortality and disability [6]. Problems that are already occurring in communities in northern Mexico (due to drought) and in the southeast (due to floods), as well as problems of violence due to the availability of resources, which will affect some physical and mental illnesses and deaths due to violence and suicides.

Interactive impacts will increase food prices, reduce household incomes, and lead to health risks from malnutrition and climate-related mortality with low or no levels of adaptation, especially in tropical regions. Food safety risks from climate change will exacerbate health risks by increasing contamination of food, crops by mycotoxins and contamination of seafood by harmful algae, mycotoxins, and chemical contaminants [6]. In Mexico, due to poverty, there are problems of malnutrition, which will be aggravated by these factors, which will lead to serious health problems, with the corresponding expenses.

4. CONCLUSION

Thus, in view of the results of the projections of scenarios at the end of the century and the forecasts made by the IPCC, it is estimated that although the particular increases in diseases at the end of the century have not yet been estimated (which requires a fine analysis and the establishment of particular projections for each disease), it is clear that all the estimates foreseen by the IPCC are already present for several decades in Mexico and it is expected that these diseases will worsen as a result of climate change, with the consequent increases in health expenditures. With the results it was possible to estimate an increase in GDP investment in the health sector that would go from 6.25% today to more than 18% at the end of the century, while per capita spending would increase from $ 1230 US dollars to more than $ 3800 dollars at the end of the century, which could perhaps be unfeasible for the national economy, since it is estimated that productivity in all three sectors would be substantially reduced by the end of the century due to the same effects of climate change. Thus, the vulnerability of the health sector in Mexico is high to very high, which puts the population at high risk.

REFERENCES

1. WHO. Climate change and health. Press center. Fact sheet No. 266. 2010. http://www.who.int/mediacentre/factsheets/fs266/es/index.html.
2. IPCC, 1995. Climate Change 1995. The Science of Climate Change Edited by J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell Production Editor: J.A. Lakeman Contribution of WGI to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. ipcc_sar_wg_I_full_report.pdf
3. IPCC, 2001: Summary for Policymakers. In: Climate Change 2001: The Physical Science Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Daniel L. Albritton, Myles R. Allen, Alfons P. M. Baede, John A. Church, Ulrich Cubasch, Dai Xiaosu, Ding Yihui, Dieter H. Ehhalt, Christopher K. Folland, Filippo Giorgi, Jonathan M. Gregory, David J. Griggs, Jim M. Haywood, Bruce Hewitson, John T. Houghton, Joanna I. House, Michael Hulme, Ivar Isaksen, Victor J. Jaramillo, Achuthan Jayaraman, Catherine A. Johnson, Fortunat Joos, Sylvie Joussaume, Thomas Karl, David J. Karoly, Haroon S. Kheshgi, Corrine Le Quéré, Kathy Maskell, Luis J. Mata, Bryant J. McAvaney, Mack McFarland, Linda O. Mearns, Gerald A. Meehl, L. Gylvan Meira-Filho, Valentin P. Meleshko, John F. B. Mitchell, Berrien Moore, Richard K. Mugara, Maria Noguer, Buruhani S. Nyenzi, Michael Oppenheimer, Joyce E. Penner, Steven Pollonais, Michael Prather, I. Colin Prentice, Venkatchalam Ramaswamy, Armando Ramirez-Rojas, Sarah C. B. Raper, M. Jim Salinger, Robert J. Scholes, Susan Solomon, Thomas F. Stocker, John M. R. Stone, Ronald J. Stouffer, Kevin E. Trenberth, Ming-Xing Wang, Robert T. Watson, Kok S. Yap, John Zillman]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. TAR-*A (ipcc.ch)
4. IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. IPCC. SPM_5.17.07FINAL.indd
5. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. WG1AR5_SPM_FINAL.pdf (ipcc.ch)
6. IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001
7. Vicedo-Cabrera, A.M., Scovronick, N., Sera, F. et al. The burden of heat-related mortality attributable to recent human-induced climate change. Nat. Clim. Chang. 11, 492–500 (2021). https://doi.org/10.1038/s41558-021-01058-x
8. IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van

Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press. https://www.ipcc.ch/srccl/chapter/summary-for-policymakers/

9. COFEPRIS (2017). Effects of Climate Change and the Derived Health Risks in Mexico Federal Commission for Protection against Sanitary Risks | December 31, 2017. Climate change and health | Federal Commission for the Protection against Sanitary Risks | Government | gob.mx (www.gob.mx)
10. World Bank Group. Climate change knowledge portal (CCKP); 2021. Available:climateknowledgeportal.worldbank.org.
11. Ebert E, McBride JL. Verification of precipitation in weather systems: determination of systematic errors. J Hydrol (Amst). 2000;239:179–202.
12. Hagemann S, Chen C, Haerter JO, Heinke J, Gerten D, Piani C. Impact of a statistical bias correction on the projected hydrological changes obtained from three GCMs and two hydrology models. J Hydrometeeorol. 2011;12:556–578.
13. Magaña V, Conde C, Sánchez O, Gay C. Assessment of current and future regional climate scenarios for Mexico. Clim Res. 1997;9:107–114.
14. Cueto RO, Tejeda A, Jáuregui E. Heat waves and heat days in an arid city in the northwest of Mexico: current trends and climate change scenarios. Int J Biometeorol. 2010;54:335–345.
15. Mitchell TD, Carter TR, Jones PD, Hulme M, New M. A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901–2000) and 16 scenarios (2001–2100). Tyndall Centre Working Paper 55. Available:www.tyndall.ac.ukTucker CJ, Pinzon JE, Brown ME, Slayback DA and others (2005) An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data. Int J Remote Sens. 2004;26:4485–4498.
16. Tucker CJ, Pinzon JE, Brown ME, Slayback DA and others. An 8 km extended NDVI AVHRR dataset compatible with MODIS and SPOT NDVI vegetation data. Int J Remote Sensing. 2005;26:4485–4498.
17. Magaña V, Conde C. Climate variability and climate change and their impacts on the freshwater resources in the border region: a case study for Sonora, Mexico. In: Diaz HF, Morehouse BS (eds) Climate and water-transboundary challenges in the Americas. Kluwer Academic Publishers, Amsterdam. 2003; 373–393. 6. INE-SEMARNAT-UNAM. The environment in Mexico 2013-2014: Atmosphere climate change. SEMARNAT; 2008. Available:http://apps1.semarnat.gob.mx/dgeia/informe_resumen14/05_atmosfera/5_2_3.html.
18. Méndez M, Magaña V. Regional aspects of prolonged meteorological droughts over Mexico. J Clim. 2010;23:1175– 1188.
19. Ichii K, Kawabata A, Yamaguchi Y. 2002: Global correlation analysis for NDVI and climatic variables and NDVI trends: 1982–1990. Int J Remote Sens. 2002;23:3873–3878.
20. Magaña V. The impacts of 'El Niño' in Mexico. UNAM Center for Atmospheric Sciences, General Directorate of Civil Protection, Ministry of the Interior; 1999.
21. Liverman DM. Vulnerability to drought and climate change in Mexico. In: Kasperson JX, Kasperson R (eds) Global environmental risk. UNU and Earthscan, New York, NY. 2001; 201–216.
22. Wilder M, Scott CA, Pineda N, Varady RG, Garfin GM, McEvoy J. Adapting across boundaries: climate change, social learning, and resilience in the United States–Mexico border region. Ann Assoc Am Geogr. 2010;100:917–920.
23. Martínez-Austria P, Patiño-Gómez C. Effects of climate change on water availability in Mexico. Water Technology and Sciences, III: 1, January-March. 2012;5-20.
24. OECD (2023), Health spending (indicator). doi: 10.1787/8643de7e-en (Accessed on 25 March 2023).
25. PAHO (2023), Social and Environmental Determinants of Health Mexico 2022. Pan American Health Organization. https://hia.paho.org/es/paises-2022/perfil-mexico.