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Evaluating How the Impacts of Climate Change on Arizona's Water Supply Will Influence Public Health

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EVALUATING HOW THE IMPACTS OF CLIMATE CHANGE ON ARIZONA'S WATER SUPPLY WILL INFLUENCE PUBLIC HEALTH

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Abstract

Over the last century, Arizona's climate has increased more than 1.1 to 1.4 degrees Celsius or 2 to 2.5 degrees Fahrenheit. The temperature in Arizona is expected to increase an additional 2.2°C to 2.8°C in the next 40 years. Climate change poses various health and environmental hazards for the residents of Arizona. One of the most significant impacts is on water supply. As temperatures continue to rise in the desert, the demand for water will increase while the water supply will reduce. A literature review and program evaluation were conducted to evaluate how the impacts of climate change on Arizona's water supply will influence public health. This evaluation will address the following questions: 1) how does climate change and urbanization affect Arizona, 2) what are the health implications of climate change on Arizona residents, 3) what are Arizona public health departments doing to prepare, and 4) what actions should the state of Arizona take to address these issues? The available literature was collected using a search strategy on PubMed, Embase, and Scopus literature database. Literature collection will include rate of temperature change, precipitation levels, water supply, air pollution, and changes in disease vectors. A program evaluation was conducted to assess the current water conservation efforts in Arizona. The various programs under the Department of Water Resources and the Arizona Department of Environmental Quality have worked diligently to develop management strategies to supply Arizona with its water supply and build its storage supplies. These programs monitor the drought status, focus on conservation efforts, protect the drinking water by ensuring compliance with the Safe Drinking Water Act, and maintains surface water quality and safety. Policy actions, conservation efforts, lifestyle and educational outreach, and water planning will need to be taken in order achieve water sustainability.

Table of Contents

Overview of Figures and Tables

Chapter 1 – Introduction

Research Question and Significance

Arizona increase in temperature is currently warming at the fourth fastest of all states in the United States based on warming rates since 1970 (“Arizona Extreme Heat”, 2016). The upward trends in temperature as well as population growth are projected to continue. The extended exposures to climate change will create various vulnerabilities for Arizona which include drier and hotter summers and a strained water supply. Arizona will continue to see higher exposures to these types of stressors due to rapid urbanization, heightened sensitivities to high water demands, and increase in residential and commercial land use (Larson et al., 2013). As Arizona’s climate continues to warm, precipitation will decrease leading to water supply shortages as well as water quality issues. A literature review and a program evaluation were conducted to evaluate the impacts of climate change on Arizona’s water supply and how that will influence public health. The program evaluation was conducted to assess the water conservation efforts that are in place in Arizona to protect water availability and quality. Specific questions from this project that were addressed include:

- How does climate change and urbanization affect Arizona?
- What are the health implications of climate change on Arizona residents?
- What are Arizona public health departments doing to prepare?
- What actions should the State of Arizona take?

Rationale for the Review

Arizona was used primarily for agriculture before the Civil War and later moved to large-scale urbanization after World War II (Larson et al., 2013; Hirt et al., 2017). The population in 1910 was just over 200,000 people (Larson et al., 2013; Hirt et al., 2017). The increase in

population and agricultural irrigation resulted in increased groundwater pumping and overdraft (Larson et al., 2013). In 2021, Arizona has a population of 7.2 million people which has increased by 13.6% from 2010 (U.S. Census Bureau, 2021). The overall climate of Arizona is arid and the average annual precipitation in the state is less than nine inches (Guhathakurta & Gober, 2007). Arizona's water supply is comprised of three main sources which included the Colorado River, the Salt and Verde River systems, and groundwater (Guhathakurta & Gober, 2007).

Long-term climate models have projected increased annual temperatures and precipitation variability in Arizona. Arizona also experiences persistent and intensive droughts. It is currently on the 27th year of a long-term drought (Arizona State Climate Office, 2022). As the climate continues to change, drought leads to various vulnerabilities to the surface and ground water supply which presents challenges for the Arizona Department of Water Resources (ADWR) and the Active Management Areas. This review aims to discuss the possible effects of climate change and urbanization on Arizona's water supply and the possible health impacts. This project will also assess what Arizona is currently doing to preserve, replenish, and recharge the water supply.

Chapter 2 – Background

Description of Health Problem

According to the U.S. Environmental Protection Agency (EPA), Arizona's climate has warmed 1.1°C to 1.4°C in the last century (EPA, 2016-b). The metropolitan area of Phoenix has seen an even higher increase in temperature in the last 50 years by about 2.2°C to 2.5°C (Dominguez, 2022). A statistical analysis conducted by (Guhathakurta & Gober, 2007), shows that increased daily low temperatures by just 0.6°C is associated with an average monthly increase in water use of 1.1 cubic meters for a typical single-family unit in Arizona. The change

in climate in Arizona has presented the state with wildfires, droughts, and heat waves (EDF, 2020). Climate change threatens the environment along with the health and economy of Arizona residents. Warmer temperatures will increase electricity bills, cause heat-related deaths, and will also lead to crop loss due to drought (Baker et al., 2002; Sullivan & White, 2020). Climate change also interacts with other trends, such as population growth, aging population, urbanization, and socioeconomic development that can exacerbate heat-related hazards (Ebi et al., 2021).

As temperatures continue to rise in the desert, the demand for water will increase and the water supply will be reduced (EPA, 2016-b). A synthesis report conducted by the Arizona Department of Health Services projects that some counties in Arizona will warm by 2.2°C to 2.8°C (Figure 1) over the next 40 years (AZDHS, 2015). Increased temperatures and lack of precipitation will greatly affect the water supply due to the increased evaporation rates (EPA, 2016-b). Lack of precipitation will also increase extreme events that include dust storms and wildfires (Bell et al., 2016; Bell et al., 2018; Ebi et al., 2021). These events will decrease the air quality due to the presence of hazardous particles and chemicals found in the wildfire smoke (LaKind et al., 2016).

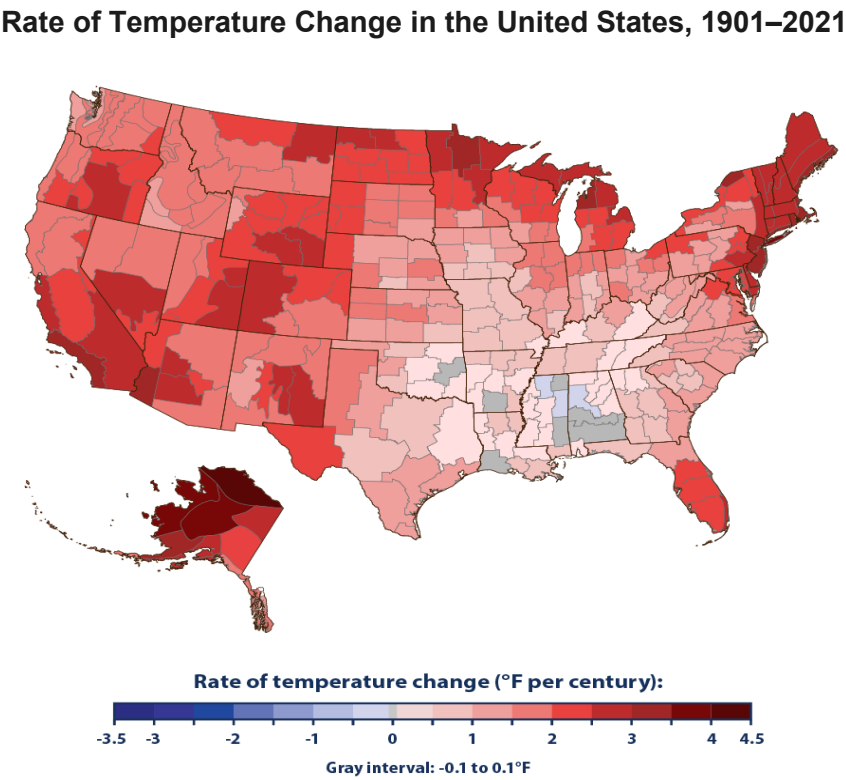

Figure 1. This figure shows how annual average air temperatures have changed in different parts of the United States since the early 20th century (since 1901 for the contiguous 48 states and 1925 for Alaska). The data are shown for climate divisions, as defined by the National Oceanic and Atmospheric Administration. (Figure source: EPA, 2021). (Data source: NOAA, 2022).

The Colorado River is the main source of water supply for the Southwest as it supplies water for 33 million people residing in metropolitan such as Los Angeles and Phoenix (Larson et al., 2013; EPA, 2017). The Colorado River reservoirs have decreased due to recent droughts, as well as decreased precipitation and snowpack (EPA, 2017; Sullivan & White, 2020). Climate-related shortages and drought coupled with policy decisions increase the vulnerability of those dependent on the river due to climate change (Sullivan & White, 2020). The impacts of climate change on the Colorado River present a health threat to Arizona residents through decreased water supply. The lower levels of precipitation and snowpack will heavily affect the water supply available during the summer months when the demand for water is at its peak (Bolin et al., 2010; EPA, 2017). Additional impacts of climate change on water supply and quality can also affect agriculture, society, energy supply, and the ecosystems (EPA, 2017). The populations

that are considered at high risk include people in a lower economic status, children, the elderly, people who participate in outdoor activities, and minorities (Ruddell et al., 2010). It is imperative that government officials and public health agencies are aware of the public health risks due to climate change and start implementing preventative measures as well as educating residents of the potentials risks (AZDHS, 2015).

Chapter 3 – Methods

Search Strategy

The literature search was conducted using the PubMed and Embase literature database. The MeSH (Medical Subject Headings) database was utilized for PubMed and the keywords included in the search were climate change, Arizona, water supply, groundwater, water resources, environmental and public health, and health status. The Emtree standardized keywords were utilized for Embase and the keywords included in the search were climate change, Arizona, ground water, water supply, environmental health, public health, epidemiology, and health status. The complete search string for each database can be found in the Table 1 and Table 2.

Table 1. PubMed Search Strings (Search Date: October 23, 2022)

	Concept	Search Terms	Hits
#1	Climate change	"Climate Change"[Mesh] OR “Climate Change”	66,647
#2	Arizona	"Arizona"[Mesh] OR Arizona	105,804
#3	Water supply	"Water Supply "[MESH] OR "Groundwater"[MeSH] OR "Water Resources"[Mesh]	47,379
#4	Public health	"Environment and Public Health"[Mesh] OR "Health Status"[Mesh]	9,802,222
	Search Strategy	("Climate Change"[Mesh] OR “Climate Change”) AND ("Arizona"[Mesh] OR Arizona) AND ("Water Supply "[MESH] OR "Groundwater"[MeSH] OR "Water	22

	Resources"[Mesh]) AND ("Environment and Public Health"[Mesh] OR "Health Status"[Mesh])	

Table 2. Embase Search Strings (Search Date: October 22, 2022)

	Concept	Search Terms	Hits
#1	Climate change	'climate change'/exp OR 'climate change'	51,882
#2	Arizona	'arizona'/exp OR arizona	2,737
#3	Water supply	'ground water'/exp OR 'water supply'/exp	73, 912
#4	Public health	'environmental health'/exp OR 'public health'/exp OR 'epidemiology'/exp OR 'health status'/exp	4,605,879
	Search Strategy	('climate change'/exp OR 'climate change') AND ('arizona'/exp OR arizona) AND ('ground water'/exp OR 'water supply'/exp OR 'ground water' OR 'water supply') AND ('environmental health'/exp OR 'public health'/exp OR 'epidemiology'/exp OR 'health status'/exp)	11

Additionally, Scopus the abstract and citation database was utilized for additional peer-reviewed literature. Two articles were selected, Vulnerability assessment of climate-induced water shortage in Phoenix by (Gober & Kirkwood, 2010) and Vulnerability of Water Systems to the Effects of Climate Change and Urbanization: A Comparison of Phoenix, Arizona and Portland, Oregon (USA) by (Larson et al., 2013). The references used by each article as well as the cited documents were manually reviewed. The review included reading over the titles and abstracts of the journals.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were utilized during the literature search with the mentioned search strategies. The inclusion criteria included date (literature published from 2000 through 2022), exposure of interest (effects of climate change, public health implications associated with climate change and water supply), geographic location of study (state of

Arizona), and language (only article in English were selected). The exclusion criteria included date (literature not published from 2000 through 2022), exposure of interest (literature that did not include effects of climate change or public health implications associated with climate change and water supply), geographic location of study (literature was excluded if it did not relate to the state of Arizona), and language (literature was excluded if it was not in English). No specifications were included on what type of study design the literature utilized.

Data Extraction / Quality Assessment

The literature results from the search strategies were imported into RefWorks, which is a citation manager. Utilizing the tools provided by RefWorks, any duplicates retrieved during the search were deleted. After the duplicates were removed, titles and abstracts of the literature were reviewed to ensure they were relevant to the research questions as well as the inclusion and exclusion criteria specified above. The literature that complied with the search criteria was then further screened to ensure full text of the literature was available. The literature was assessed for quality by manually reading the available abstracts and articles.

Chapter 4 – Results

Search Results / Evaluation Findings

The PubMed search strategy provided a total of 22 results. A total of 10 articles were selected after reading the abstracts due to matching the research questions and inclusion criteria. 12 articles were excluded because they did not match the inclusion criteria and were irrelevant to the research questions. The Embase search strategy provide a total of 11 results. Only one article was selected after reading the abstracts of each journal. Due to the specificity of the search strategy a low number of journals matched the inclusion criteria which is why Scopus was utilized for two articles.

The article by (Gober & Kirkwood, 2010) was cited by 93 documents and had 38 references. After manually reviewing the titles and abstracts of these documents a total of eight journals from the article's references and eight journals from the cited documents were selected. The article by (Larson et al., 2013) was cited by 26 documents and had 59 references. After reviewing the titles and abstracts seven journals from the article's references and five journals from the cited documents were selected.

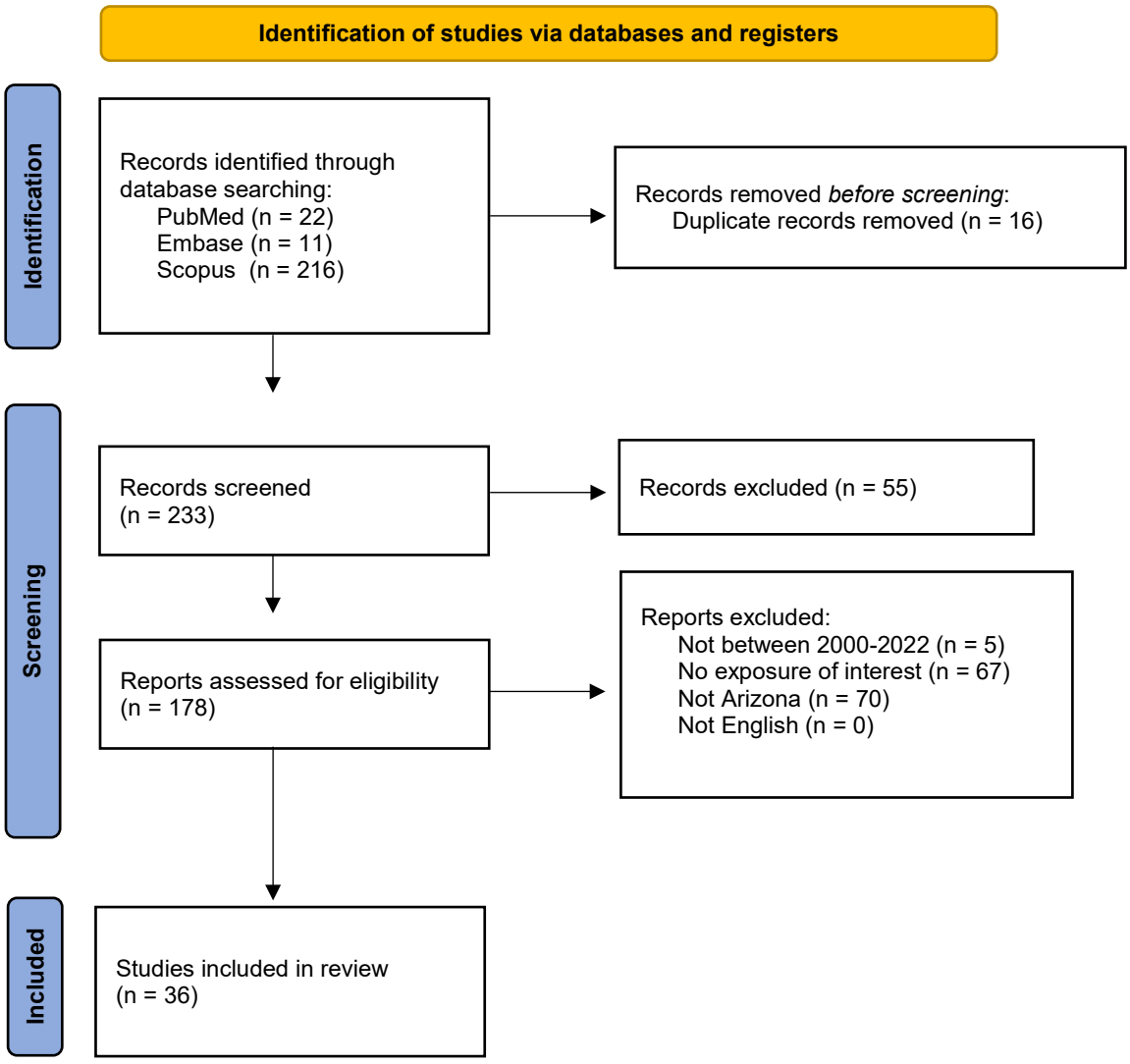

Figure 2. PRISMA diagram showing study attrition

Public Health Risks Influenced by Climate Change

High Temperatures

Extreme heat has been the leading cause of weather-related mortality in the United States for the past 30 years (Kalkstein & Sheridan, 2007; NOAA, 2022). Studies continue to show a strong relationship between high temperatures and all-cause mortality (Harlan & Ruddell, 2011). Rising temperatures have been directly linked to human health which include heat exhaustion, heat stroke, and death (Ebi et al., 2021). Arizona has seen an increase in its "misery hours" per day due to urban heat island effects (Baker et al., 2002). Urban heat island dynamics also have the potential to increase water demands in Arizona through larger lot sizes in residential areas (Guhathakurta & Gober, 2010; Larson, et al., 2013). The increase in "misery hours" (hot part of summer days) increases heat stress on humans and plants, reduces the quality of crops and production, and broadens the thermal window for arthropods (Baker et al., 2002). (Baker et al., 2002) analyzed the temporal and spatial data sets for Arizona. The results from the study revealed that the minimum daily temperatures are increasing and the time to reach "misery hours" during the day has decreased.

Increased Mortality / At-risk Population

Arizona averages around 30 heat-related deaths per year, which is about 13 times the national rate (Baker et al., 2002). Increases in temperature can also disrupt health systems and services due to an increase in patient volume (Ebi et al., 2021). Additional studies will need to be conducted on how hot weather effects hospitalizations and emergency department visits as well as the social impacts heat has on a population (Kalkstein, 2007). The Centers for Disease Control and Prevention (CDC) reported a total of 10,527 heat-related deaths during 2004 to 2018 in the United States (Vaidyanathan et al., 2020). Approximately 90% of these deaths occurred during May-September. Residents of Arizona, California, and Texas account for only

approximately 23% of the U.S. population, but these three states accounted for approximately one third (3,852; 37%) of heat-related deaths (Vaidyanathan et al., 2020). Two thirds of heat-related deaths occurred in males. Table 3 from (AZDHS, n.d.-b), shows the number and rate of heat-caused and heat-related deaths in Arizona residents. The highest heat-caused deaths were observed in 2020 and 2021 with 207 deaths in 2020 (2.9 per 100,000 population) and 185 deaths (2.5 per 100,000 population) in 2021. 2020 and 2021 were also the years with the highest heat-related deaths. 378 heat-related deaths (5.3 per 100,000 population) occurred in 2020 and 414 heat-related deaths (5.8 per 100,000 population) occurred in 2021. Table 4 from (AZDHS, n.d.-b), shows the number of heat-related deaths by race/ethnicity. During 2011 through 2021, non-Hispanic whites had the highest number of heat-caused deaths which was 822 followed by Hispanic/Latino who had a total of 548 heat-caused deaths. The years with the most deaths by race/ethnicity were 2020 and 2021.

With the rapid urban development observed in Arizona, residents' health and comfort will continue to be impacted due to the temperature extremes. Exposure to these temperature extremes will become more frequent and last for longer periods of time which will test human tolerances to heat (Ruddell et al., 2010; Harlan & Ruddell, 2011). A study conducted by (Ruddell et al., 2010), examined extreme heat as an urban hazard in Phoenix, Arizona. The results from this study indicated that residents at highest risk of exposure to extreme heat and heat-related illnesses were the elderly, minority, and low-income residents. Unfortunately, the residents at highest risk would also have fewer economic resources to help alleviate their exposure during the extreme high temperatures. Other persons with a high risk of exposure to experience physiological heat strain and heat-related illness include outdoor workers who work in agriculture or construction (Ebi et al., 2021).

Table 3. Heat-caused & heat-related deaths in Arizona residents by year 2011–2021

Deaths from Exposure to Excessive Natural Heat				
Year	Heat – Caused Deaths		Heat – Related Deaths	
	Count	Rate (per 100,000)	Count	Rate (per 100,000)
2011	57	0.9	108	1.7
2012	53	0.8	109	1.7
2013	56	0.8	96	1.4
2014	32	0.5	74	1.1
2015	42	0.6	88	1.3
2016	98	1.4	165	2.4
2017	105	1.5	227	3.2
2018	92	1.3	187	2.6
2019	117	1.6	220	3.0
2020	207	2.9	378	5.3
2021	185	2.5	414	5.8

Heat-caused deaths are deaths where the primary cause of death is listed as exposure to excessive natural heat. Heat-related deaths are deaths where exposure to excessive natural heat is listed anywhere on the death record and include those that were heat-caused. Rates calculated here use the 2020 Vintage estimates from US Census for 2011-2019; Vintage 2021 estimates from US Census were used to calculate rates for 2020-2021. (Source: AZDHS, n.d.-b)

Table 4. Heat-caused deaths,* by race/ethnicity— Arizona, 2011–2021†

		Total	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
State or Country of Residence	Arizona Resident	1044	57	53	56	32	42	98	105	92	117	207	185
	Non-Arizona Resident	592	66	44	47	16	41	48	27	37	43	106	117
Geographic Region of Occurrence	Central Counties	829	61	55	45	27	39	69	67	76	101	161	128
	Northern Counties	170†	7	0	13	*	*	12	33	19	23	54	66
	Southern Counties	558	55	41	45	18	39	60	32	34	34	95	105
	Western Counties	20†	0	*	0	0	*	*	0	0	*	*	*
Race/Ethnicity	American Indian/ Alaskan Native	60†	*	*	6	0	0	0	11	6	6	11	13
	Asian or Pacific Islander	20†	0	*	0	0	*	*	*	*	*	*	*
	African American/Black	80†	6	*	6	*	*	*	*	7	9	20	21
	Hispanic/Latino	548	59	43	43	16	32	52	28	35	41	90	109
	White Non-Hispanic	822	53	46	48	28	44	81	77	70	74	152	149
	Unknown	110†	0	0	0	*	*	10	12	10	26	37	7

Notes: † Sum rounded to nearest tens unit due to non-zero addend less than 6; * Number of deaths related to exposure to excessive natural heat were suppressed due to non-zero count less than 6. Classification of geographic regions: Central = Gila, Graham, Maricopa, Pinal, and Yavapai; Eastern = Greenlee; Northern = Apache, Coconino, Mohave, and Navajo; Southern = Cochise, Pima, Santa Cruz, and Yuma; Western = La Paz. (Source: AZDHS, n.d.-b)

Droughts

As mentioned earlier, Arizona has been experiencing long-term drought. In July of 2021, 99% of the state was considered in a drought (Di Liberto, 2021). Arizona receives its annual rainfall two times a year which occurs in the summer during monsoon season and in the winter. In the past year, the precipitation levels were not as expected which created a hot summer and a poor monsoon season (Di Liberto, 2021). As indicated in Figure 3, Arizona experienced the driest monsoon season on record in 2020. In addition, the winter snowpack that Arizona normally receives was affected by the Upper Colorado basin which also contributed to the drought (Di Liberto, 2021).

One primary health ramification that can occur from droughts and climate change is the depletion and potential contamination of available water sources (CDC,2010; Bell et al., 2016). Drought is known to produce ideal conditions to promote the growth of various pathogens due to stagnant, warm water (Ebi et al., 2021). Drought has and will continue to be a significant climatic issue that Arizona will need to address through reducing water consumption, controlling population growth, and policy evaluation and action (Hirt et al., 2017). The effects of climate change are expected to increase the frequency, intensity, and duration of drought which presents concerns about the sustainability of water resources (Gober et al., 2016).

Arizona has not had to endure the effects of drought conditions due to the variety of sources it receives water from, the steady shift of agricultural lands and the transfer of water to urban areas as mandated by the Groundwater Management Act, as well as the water deliveries from the CAP (Gober et al., 2016). The major concern water managers will need to address is the reduction of CAP water due to the original agreement among the lower Basin States (Gober et al., 2016).

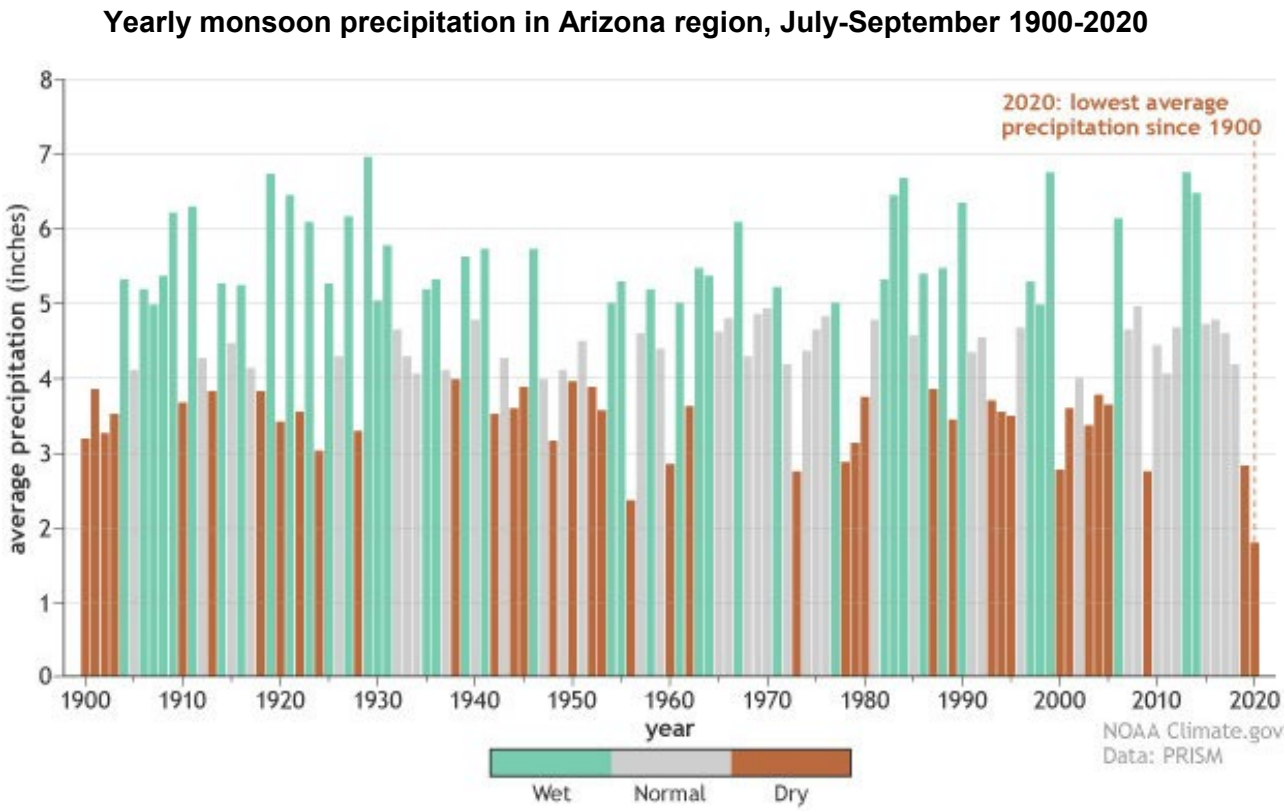

Figure 3. Summer (July–September) rainfall totals for the greater Arizona region from 1900-2020. Brown years are among the driest third of monsoons, gray represents the middle third, and blue reflects the wettest third. 2020 was the driest on this record. NOAA Climate.gov image, using data provided by Mike Crimmins at the University of Arizona. (Figure source: https://www.climate.gov/news-features/event-tracker/western-drought-2021-spotlight-arizona)

Health Impacts

As the temperatures continue to increase in Arizona, residents will be exposed to extreme heat and various health hazards (AZHDS, 2015). “Exposure to elevated temperatures can raise the core body temperature and can also worsen health conditions like heart disease and respiratory illness” (AZDHS, 2015). Occupational heat stress has been hypothesized to contribute to chronic kidney disease (Ebi et al., 2021). A journal by (Johnson et al., 2016), looked at the relationship between dehydration and chronic kidney disease. People who work in hot environments acclimate by having a higher sweat rate which leads to increased water loss. People who work in hot environments and are exposed to heat stress, double their risk for developing chronic kidney disease (Johnson et al., 2016). Additional health impacts associated

with climate change include dust storms, fungal diseases, water-borne diseases, vector-borne diseases, and respiratory diseases (Baker et al., 2002; Harlan & Rudell, 2011; AZDHS, 2015; Bell et al., 2016). As temperatures in Arizona continue to rise, residents may see an increase in various water-borne diseases like cryptosporidium and naegleria fowleri (Stanford, 2017; Brunkard & Carter, 2022). In 2016, Arizona had a total of 523 confirmed and probable cases of cryptosporidiosis from recreational water activities. Residents can also become infected through drinking ground water that has become contaminated from runoff from urban areas or farming after flooding (CDC, 2019).

Another impact of climate change on health is air pollution. Pollutants can affect a variety of disease categories which include respiratory and cardiovascular illnesses (Harlan & Rudell, 2011; Ebi et al., 2021). The increased particulate matter in the atmosphere because of drought and high winds can lead to respiratory health issues and death. Intense drought and increased temperatures in Arizona can lead to respiratory illness such as coccidioidomycosis (also known as Valley fever) (Pfaller et al., 2006; Bell, et al. 2016; Ebi et al., 2021). This fungal disease grows in soil after rainfall and becomes airborne during hot, dry conditions (Smith et al., 1946; Bell et al., 2016). Dust storms have also been linked with respiratory issues which include asthma, acute bronchitis, and pneumonia (Heffling et al., 1994; Grineski et al., 2011; Panikkath et al., 2013; Bell et al., 2016). These powerful windstorms can irritate the upper respiratory system, cause chronic breathing issues as well as heart disease.

The higher temperatures and longer thermal window due to climate change allows for disease vectors to thrive in new geographical locations and allows for an increase in their population (Baker et al., 2002; Comrie, 2007; Bell et al., 2016; EPA, 2016-b). West Nile Virus (WNV) exposure can increase during droughts due to birds and mosquitoes converging near any available water sources (Shaman et al., 2005; Bell et al., 2016). In 2021, Arizona had 1,693 confirmed and probable cases of West Nile Virus (AZDHS, 2022). Hantavirus Pulmonary

Syndrome is another known issue in Arizona. Heavy rainfalls after drought have been associated with increase in rodent populations. The rainfalls along with climate variability, and wet winters provide vegetation and food supplies for the rodents (Comrie, 2007). During prolonged drought conditions, rodents may become displaced and seek out resources which in turn increase rodent-human contact exposure. Rodents expose residents to Hantavirus through the aerosolization of their droppings and urine in and around homes (Comrie, 2007).

Environmental / Economic Risks Influenced by Climate Change

The United Nations reported that "current freshwater supplies may only meet 60% of the world's population needs by the year 2030" (United Nations, 2016; Hirt et al., 2017). The report also mentions that climate change, population growth, and policies that prioritize economic development over conservation are the driving forces behind a global water deficit" (Hirt et al., 2017). As discussed earlier, some of Arizona's farmland is being converted for urban land use. Shifting water from farms to supply cities creates new social and economic risks (Larson et al., 2009; Gober & Kirkwood, 2010). In times of drought, if farmers lose access to water, they have the option of delaying the planting of crops or they can choose not to plant their crops at all (Hirt, et al., 2017). Households and businesses are reliant on municipal water supply, and it is not feasible to cut access or shift water supply from residents during a drought (Larson et al., 2009). Doing so would greatly impact the residents and businesses in that region and would also be very costly (Larson et al., 2009). As agricultural land use decreases and rapid urbanization increases, the opportunity for new development also increases, which can lead to encroachment on desert land that may lack water rights or accessible water supply (Larson et al., 2009).

Drought poses economic and societal consequences on urban development (Cayan et al., 2010). Water is used for food production, urban development, and economic prosperity

(Wang & Vivoni, 2022). Municipalities within metropolitan areas complicate water security planning because these municipalities may differ in political and economic power or structure and may influence the water rights seniority (Rushforth et al., 2020). The increase in population in urban areas, the replacing of agricultural land and the natural desert with new developments are inadvertently heating up these municipalities due to urban warming. The impacts of urban warming include increased minimum daily temperatures, longer warm periods and shorter cool periods during the day, and an extended hot season (Baker et al., 2002). The effects of urban warming can have a negative effect on agriculture which could lead to lower food output.

Program Evaluation of Arizona's Water Conservation Efforts

To ensure residents of Arizona are supplied with fresh drinking water the Arizona Department of Water Resources (ADWR) and the Arizona Department of Environmental Quality (ADEQ) work together to protect and enhance Arizona's water supplies. The ADWR has multiple programs in place to help protect and conserve water supply. These programs include Active Management Areas (AMAS), Assured and Adequate Water Supply, Colorado River Management, Community Water Systems, Conservation, Drought Committees and Groups, Recharge Program, and the Water Protection Fund. Each one of these programs has certain roles and responsibilities to protect water supply.

The ADWR drought management program has been monitoring the drought status in Arizona on a weekly, monthly, and quarterly basis (ADWR, 2022-c). The drought management program along with the Colorado River Management program have been working together to protect and prevent water shortages to the Colorado River system and Lake Mead's elevation from dropping to critical levels (ADWR, 2022-c). Due to the prolonged drought Arizona has been experiencing, the Governor's Drought Task Force was created in 2003 and a Drought Preparedness Plan was developed and adopted in 2005 (ADWR, 2022-b). Key components of

the Drought Preparedness Plan include guidelines for more efficient use of water, focusing on conservation tools, promoting water education, and providing funding and implementation of conservation programs.

The Active Management Areas were created to manage Arizona's groundwater resources. There are five areas in Arizona that were identified as AMAs due to their heavy reliance on groundwater (ADWR, 2022-a). The primary management goal of three of the five AMAs is to reach safe-yield by 2025 (ADWR, 2022-a). Safe-yield would ensure no groundwater is being mined if it can't be replaced annually. Active Management Areas must comply with regulatory requirements that are dictated by the Arizona Groundwater Code which include mandatory conservation requirements (ADWR, 2022-a). In 2022, the governor of Arizona signed legislation that provides $1 billion to secure Arizona's future water supply (Office of the Arizona Governor, 2022). The money will fund projects that will work on brining additional water to Arizona and ensure residents, businesses, and agriculture continue to thrive and have access to adequate water supplies (Office of the Arizona Governor, 2022). The funds will go to the Water Infrastructure Finance Authority (WIFA) who will be responsible for providing loans and grants to water providers who focus their efforts on conservation, new technologies, and importing water into Arizona (Office of the Arizona Governor, 2022).

The focus of the Recharge and Recovery Program has historically been to encourage and enable the beneficial use or renewable supplies through annual storage and recovery, long-term storage for future demands and replenishment. The 5th Management Plan for Phoenix has started to shift its focus from storage for future demands to recovery for current demands due to climate change impacts on water availability (Fifth Management Plan, 2020). As the state continues to become drier, recharge and recovery will continue to be a significant water management tool for Arizona. The state will need to shift toward other types of recharge as

shortage limits the availability of Colorado River supplies and leverage existing storage capacity (Fifth Management Plan, 2020).

The Water Quality Division (WQD) under ADEQ protects and enhance public health and the environment by ensuring healthy drinking water is provided by public water systems and by controlling current and future sources of surface and groundwater pollution (ADEQ, n.d.). The WQD ensures the protection of Arizona's drinking water by ensuring compliance with the Safe Drinking Water Act. The WQD also conducts assessments of all public water sources and assesses quality of water by testing for potential contaminations (ADEQ, n.d.). The ADEQ is also in charge of issuing Aquifer Protection Permits (APP) to safeguard Arizona's groundwater. ADEQ will control the discharge of pollutants from facilities as well as regulate the direct reuse of reclaimed water (ADEQ, n.d.). ADEQ maintains and enhances the surface water quality by implementing a variety of programs from the Clean Water Act and Arizona's Water Protection Program. The overall water quality is measured against standards that ensure safety and protect the environment (ADEQ, n.d.).

The various programs under the Department of Water Resources and the Arizona Department of Environmental Quality have worked diligently to develop management strategies to supply Arizona with its water supply and build its storage supplies. By investing resources into water conservation, infrastructure, and reuse of water, Arizona has been able to maintain the same water usage rates from more than half a century ago with an increasing population (ADWR, n.d.). Arizona's water management success can be seen in figure 4. In 1957, the population of Arizona was roughly 1.5 million and the water usage was about 7 million acre-feet. In 2019, the population rose to about 7.5 million and the water usage was slightly over 6.5 million acre-feet. The creation of the Arizona Department of Water Resources in 1980 greatly helped Arizona with its water management and conservation efforts as depicted in the figure

below. Arizona has also been able to conserve its water by requiring water users to participate in mandatory water conservation (ADWR, n.d.).

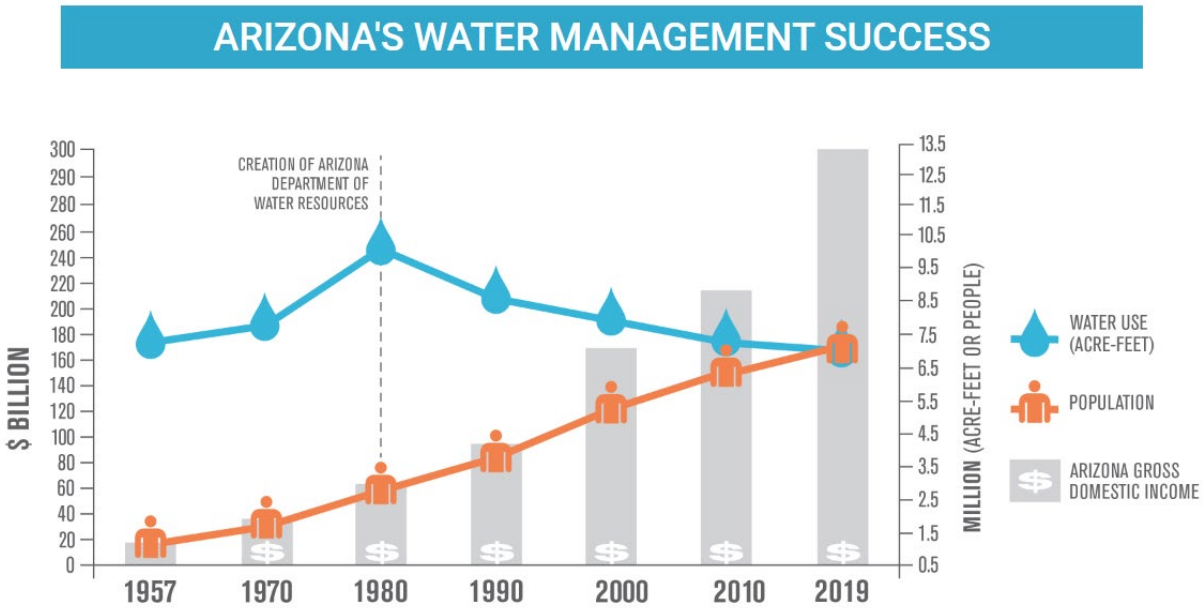

Figure 4. Arizona's water management success from 1957-2019. Population totals and water use (acre-feet) are shown for each year. The increase in population has not increased water use since the creation of the Arizona Department of Water Resources in 1980. (Figure source: https://www.arizonawaterfacts.com/water-your-facts

The literature review provided additional actions water managers and legislators can take to better protect and conserve the available water resources. Population growth will continue to intensify competition for water resources mainly between municipal and agricultural users. According to (Gober & Kirkwood, 2010) policy actions need to be taken to achieve water sustainability in 2030. Additional changes include lifestyles changes and slowing the rate of population growth in Arizona. The analysis conducted by Gober & Kirkwood (2010) shows Arizona should move from precaution to anticipation when it comes to water planning due to the uncertainty on how much water will be available from the Colorado and Salt/Verde systems. A study conducted by (Guhathakurta & Gober, 2007) discussed how the urban heat island effect contributes significantly to water use in single-family homes and concluded Arizona should invest in planning research and practice to combat urban waste heat to address climate and

water use. (Hirt et al., 2017) discussed the importance of evaluating the Groundwater Management Act of 1980 and ensuring underground aquifers are not being mined to help mask the water crisis. As states along the Colorado River Basin started to divert more water from the Colorado River than its annual flow, this caused Lake Powell and Lake Mead to be greatly utilized causing historically low water levels (Hirt et al., 2017). The Bureau of Reclamation expects that both reservoirs will continue to decline.

Some actions that water managers and legislators in Arizona could improve on include conservation measures, water planning, educational outreach, and lifestyles changes, prioritizing water supply over economic development, and limiting or slowing the rate of population growth. The 2019 Drought Contingency Plan (DCP) has been created to protect the Colorado River through voluntary reductions and increased conservation (CAP, 2022). The DCP requires reductions and conservation for different tiers. Given that Arizona has been in a prolonged drought for the past 22 years and is very dependent on the Colorado River for its water supply, it would be beneficial for the state to be conserving water regularly and more frequently. In regard to educational outreach and lifestyle changes, Arizona municipalities have created flyers and handouts which provide residents information on how they can conserve water. Instead of waiting for drought conditions to worsen to implement residential conservation efforts, municipalities should be promoting conservation efforts. Arizona also needs to adapt to some lifestyle changes that include limiting what the water supply is used for. Arizona is an arid region but residential homes are equipped with grass, swimming pools, and golf courses (Hirt et al., 2017) which require significant amounts of water. Arizona should also limit the amount of economic development occurring. The variety of businesses and manufacturing plants (data centers, microchip plants) that have broken ground in Arizona all require water. Arizona should be working towards conserving its water supply instead of straining it.

Chapter 5 – Discussion

Summary

Arizona is experiencing higher temperatures that puts Arizona residents at risk for various health issues which include heat stress, cardiovascular disease, water-borne disease, and vector-borne disease. Residents can be exposed to these diseases through air pollution and dust storms caused by climate change. Water managers in Arizona face a variety of challenges to supply water to the state due to climate change, ongoing drought, and rapid urbanization. Although the literature provided ample information, further studies should be conducted to evaluate the health risks associated with climate change and the declining water levels of the Colorado and Salt/Verde systems.

Public Health Implications

This review was able to provide abundant findings related to the public health implications associated with climate change and the necessary actions water managers should take to alleviate Arizona's vulnerabilities. The first health implication residents of Arizona will be exposed to are higher temperatures due to climate change. The rapid urbanization in Arizona has increased the "misery hours" for people. The second health implication is heat-related deaths. Residents of Arizona, California, and Texas account for only approximately 23% of the U.S. population, but these three states accounted for approximately one third (3,852; 37%) of heat-related deaths (Vaidyanathan et al., 2020).

Another health implication is the prolonged drought in Arizona. Arizona receives its annual rainfall two times a year which occurs in the summer during monsoon season and in the winter. In the past year, the precipitation levels were not as expected which created a hot summer and a poor monsoon season (Di Liberto, 2021). The health ramifications that can occur

from droughts and climate change include the depletion and potential contamination of available water sources (CDC, 2010; Bell et al., 2016). Drought is also known to produce ideal conditions to promote the growth of various pathogens (Ebi et al., 2021). The final health implications include various health diseases that are associated with climate change. Additional health impacts associated with climate change include dust storms, fungal diseases, water-borne diseases, vector-borne diseases, and respiratory diseases respiratory diseases (Baker et al., 2002; Harlan & Rudell, 2011; AZDHS, 2015; Bell et al., 2016).

Strengths and Limitations

One of the strengths of this review was the systematic literature review. Utilizing a search strategy and reviewing the abstracts of each journal provided sound literature. One limitation of this review was the specificity with of geographic location. Additional and more recent studies would have been beneficial and would have allowed for a more in-depth evaluation of the impacts of climate change. Also, certain health impacts are hard to study due to confounding affects (i.e. social economic status, health-related deaths). Another possible limitation of this review is the inclusion criteria of the literature not exceeding 20 years from date of publication.

Recommendations

Although, Arizona water managers have been working hard to develop various management strategies to build up Arizona's water and storage supply, additional actions will need to be taken to ensure adequate supply is available in the future. The results from this literature review indicated that policy actions need to be taken to achieve water sustainability in 2030 (Gober & Kirkwood, 2010). Additional actions will need to include increased conservation measures, water planning, educational outreach, and lifestyles changes, improving irrigation methods, increased monitoring, and implementing water-use restrictions. The analysis

conducted by Gober & Kirkwood (2010), shows Arizona should be moving from precaution to anticipation when it comes to water planning due to the uncertainty on how much water will be available from the Colorado and Salt/Verde systems.

Arizona municipalities and land development planners can increase conservation efforts by requiring the utilization of xeriscape. Xeriscape is the practice of landscaping that reduces or eliminates the need for irrigation by using rocks and native or desert-adopted plants (Rutledge et al., 2022). Local counties requiring native plant species as well as artificial turf can decrease their water usage due to the vegetation not requiring additional levels of irrigation. Native and low-water-use plants are drought tolerant, as well. Land development planners can also limit the amount of golf courses or swimming pools allowed in residential areas. Regarding irrigation, residents should utilize drip irrigation instead of spray sprinkler heads. Residents and businesses can also be encouraged to use rain sensors and timers to prevent overwatering plants. Other items including passive rainwater collection, avoiding fountain fixtures in landscaping designs, and ensuring vegetation is watered in the morning or evening.

Arizona residents should be urged to alter their lifestyle and habits through educational outreach. A major component of educational outreach should focus on outdoor safety. As stated before, heat is the leading cause of weather-related mortality in the U.S. Studies have shown a strong relationship between high temperatures and all-cause mortality (Harlan & Ruddell, 2011). Educational outreach should inform Arizonians of the signs and symptoms associated with heat exhaustion and heat stroke. It should also include safety precautions and messages for anyone who might spend extended time outdoors during the “misery hours” like farmers, construction workers, persons without housing, and athletes. Additional educational outreach should provide residents the reasons why water conservation is so vital and what is happening with the current water supply. Municipalities can provide residents with conservation kits equipped with water-saving fixtures. Simple lifestyle and habit changes include shorter showers, limiting the number

of times the toilet is flushed, utilizing greywater from showers or hand washing, and turning off the water when not in use. Arizona municipalities need to shift their focus on more intensive conservation efforts instead of waiting for the drought status to worsen. Actions that can be implemented include water-use restrictions and water-use caps. Municipalities can enact limits on outdoor watering or car washing. Water-use capping for households and businesses would help residents monitor their water usage and entice them to fix any leaking plumbing. Any water-use overages would be accompanied by a fee.

The Arizona Department of Health Services (ADHS) created the Extreme Weather and Public Health Program to "combat extreme weather events which include heat waves, dust storms, flooding, drought and adverse air quality events" in Arizona (AZDHS, n.d.-a). In 2016, the Extreme Weather and Public Health program was awarded a grant through the CDC Climate-Ready States and Cities Initiative to build public health resilience against the various hazards Arizona residents are exposed to (AZDHS, n.d.-a). This "initiative allows for AZDHS to develop ways to anticipate health effects by applying climate science, predicting health impacts, and preparing flexible programs by incorporating CDC's Building Resilience Against Climate Effects (BRACE) Framework (AZDHS, n.d.-a)." "The BRACE framework is a five-step process that allows health officials to develop strategies and programs to help communities prepare for the health effects of climate change (CDC, 2020)." Arizona's continued participation in this program allows for the implementation of public health interventions which will protect Arizonans against climate-sensitive hazards (AZDHS, n.d.-a). Some of the interventions Arizona has been able to implement include the Arizona Extreme Weather, Climate and Health Profile Report which describes the health risks from air pollution, extreme heat, drought, and vector-borne diseases in Arizona. Additional interventions included the Assessment of Climate and Health Impacts on Vector-Borne Diseases and Valley Fever in Arizona which reported on climate effects on vector-borne diseases and identified populations who were at greatest risk.

Additionally, ADHS has developed the Arizona Climate and Health Adaptation Plan (ACHAP) as part of their grant initiative through the CDC. ADHS intends to “support interventions and enhance public health preparedness activities related to climate hazards and minimize adverse impacts through the coordination of the ACHAP (Roach et al., 2017).” The ACHAP is a “collaborative process with various stakeholders and researchers that play a role in protecting public health by building resilience against the effects of climate hazards (Roach et al., 2017).” The ACHAP allows for federal, state, and local government agencies, Native American tribal governments, universities and colleges, and healthcare organizations to participate in climate and health workshops to streamline communication to implement an effective plan to protect the overall health of Arizona residents (Roach et al., 2017). Specific activities of the ACHAP include periodic assessments of the community’s health status using methods that can compile data that can be used to communicate any hazards and effects on health (Roach et al., 2017). Another activity is identifying and investigating any health threats to provide ample time to address any major health problems. This will also help stakeholders with surveillance of vector-borne pathogens associated with climate change. Additional activities include developing policies and plans that support community health and the enforcement of laws and regulations that ensure safety (Roach et al., 2017). Local municipalities and tribal organizations should be encouraged to develop local climate and health adaptation plans for their communities as well as contribute to the statewide plan (Roach et al., 2017). Arizona laws should be reviewed and evaluated to ensure compliance in relation to climate-related health threats. Local municipalities and organizations can track and lobby for new climate legislation related to health issues to ensure the public is protected.

Conclusions

The literature review provided insight into the vulnerabilities and health impacts Arizona is exposed to due to climate change. Water manager needs to switch their approach from

annual storage to recovery to ensure future water demands can be met for the rapidly growing population and ensure the water supply is protected from climate change impacts.

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Appendix A: Biography & CV

Patricia Wrona is a Master of Public Health student at the University of Nebraska Medical Center College of Public Health. Her studies have focused on environmental health, emergency preparedness, and epidemiology. Ms. Wrona is an Environmental Health Officer with the Indian Health Service (IHS) in Tempe, Arizona. She has been with the IHS since 2015 and is a Commissioned Officer with the U.S. Public Health Service. Ms. Wrona has a Bachelor of Science in Environmental Health from Illinois State University and is currently pursuing her Certificate in Emergency Preparedness from the University of Nebraska Medical Center.

Curriculum Vitae
LT Patricia Wrona, MPH, BS, RS

Education & Professional Credentials

Education

University of Nebraska Medical Center Omaha, Nebraska	Graduate Certificate Emergency Preparedness	2023 (expected)
University of Nebraska Medical Center Omaha, Nebraska	Master of Public Health Environmental & Occupational Health	2022
Illinois State University Normal, IL	Bachelor of Science Environmental Health	2013

Professional Credentials

Registered Sanitarian	2014 - 2022
ServSafe Certified Food Manager, Instructor, and Proctor	2016 - 2026
Certified Child Passenger Safety Technician	2016 - 2022
OSHA 30-Hour Outreach for General Industry	2021

Career Progression & Mobility

		Rank(s) Held
2018-Present	Environmental Health Officer Indian Health Service (O-4 billet) Office of Environmental Health & Engineering, Tempe, AZ	O-3
2015-2018	Environmental Health Specialist Indian Health Service (O-4 billet) Office of Environmental Health & Engineering, Tempe, AZ	GS-09
2014-2015	Environmental Health Specialist Maricopa County Environmental Health Division, Mesa, AZ	N/A
2013	JR COSTEP Sanitarian Indian Health Service (O-1 billet) Phoenix Indian Medical Center, Phoenix, AZ	O-1

Leadership Positions Held

- EHOPAC, Marketing & Recruitment Subcommittee, Co-Lead 2021-Present
- IHS Phoenix Area Awards Board Voting Member 2021-Present
- IHS Leadership Development Cohort 2020
- Mentor – JRCOSTEP 2017, 2019
- Injury Prevention Pilot Project (Opioid Abuse Prevention), Field Coordinator 2018
- Advanced Food Safety Training Program, District Lead 2017-Present

Professional Experience

Field Environmental Health Officer **O-4 Billet**
Indian Health Service Nov 2015–Present
Phoenix Area, Western Arizona District Office, OEHE
Tempe, Arizona

Duties/Collateral Activities

- Design and deliver technical trainings which include advance food safety (certified food manager), basic food handler, OSHA hazard communication and blood-borne pathogens, infection control, occupational safety, communicable disease control, and emergency management.
- Conduct comprehensive environmental health and safety assessments of establishments and complex institutions including: restaurants, food processing facilities, detention centers, senior centers, hotels/motels, swimming pools/spas, cosmetology facilities, and childcare centers.
- Create technical reports citing national standards which include NFPA, OSHA, and FDA.
- Provide recommendations during inspections to prevent health and safety hazards from occurring onsite.
- Review operational health and safety policies of various establishments and complex institutions to ensure compliance.

Environmental Health Specialist **N/A**
Maricopa County April 2014–Oct 2015
Environmental Health Division
Mesa, Arizona

Duties/Accomplishments

- Conducted over 1,300 unscheduled and follow up inspections of public establishments for compliance with environmental rules and regulations.
- Provided training and educational support to operators on proper food handling methods, sanitization, food-borne illnesses along with other good retail practices.
- Produced inspection reports to help assess compliance with sanitary code and documented violations.

COSTEP Sanitarian (90 days) **O-1 Billet**
Indian Health Service May 2013–Aug 2013
Phoenix Indian Medical Center
Phoenix, Arizona

Duties/Accomplishments

- Conducted code red drills, ergonomic assessments, and chemical sampling in various departments.
- Worked on safe patient handling and movement project for the hospital.
- Accompanied the Indian Health Service Health Department on various food, casino, and day care inspections.
- Presented blood-borne pathogen PowerPoint's at education centers, administered vaccines at rabies clinics, and informed residents living on reservations concerning the Rocky Mountain Spotted Fever.

Addendum (Professional Activities)

Publications

1. 2021, Tsatoke A., Morones R., Ampadu I., et al., Prescription drug safe storage practices in Arizona tribal communities, British Medical Journal
2. 2018, Wrona P. & Garcia V., Partnering with Special Events to Reduce Food Safety Violations, IHS DEHS Annual Report

Presentations

1. 2021, Co-Author, Senior Centers and Elder Nutrition Programs, Inter Tribal Council of Arizona, Virtual
2. 2021, Co-Author, The Role of Environmental Health in Opioid Prevention, 2021 Virtual Sanitarians' Conference, Virtual
3. 2021, Co-Author, How to Use Data to Build a Program, AZDHS Tribal Opioid & Substance Use Conference, Virtual
4. 2018, A Look Inside Health and Safety in Cosmetology, Phoenix Area IHS Workshop, Phoenix, AZ