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Review of water scarcity assessments: Highlights of Mexico's water situation

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Abstract

This article examines the situation of water scarcity and security in Mexico, with a focus on the drinking water supply issue in rural communities and the challenges posed by assessment methodologies. We conducted a comprehensive literature review to update the available information on the water crisis in Mexico and its impact on rural communities in the country, as well as the methodologies employed to assess water security and the methodological challenges associated with them. Among the most noteworthy findings is the persistent challenge in evaluating water scarcity and its implications for communities, due to the lack of consensus on the most precise methodology. Nevertheless, current methodological approaches suggest the integration of physical models with pertinent social, economic, and political data. The literature broadly agrees on the severity of the water scarcity crisis and the clear link between rural poverty and inadequate access to drinking water. Water scarcity is both a contributing factor to and a consequence of poverty, stemming from a complex interplay of socioeconomic pressures, inadequate institutional responses, and deficient water management. The paper concludes that water scarcity involves intricate interactions among various factors, encompassing physical water scarcity, pollution, and the impacts of climate change on the water cycle, and most critically, the complexities inherent in water management and regulatory frameworks. Therefore, the integration of well-informed policies, effective management practices, and collaborative efforts is crucial for ensuring a prosperous and sustainable future. Effective water management can effectively mitigate the challenges of water scarcity and alleviate poverty.

This article is categorized under:

Engineering Water > Water, Health, and Sanitation
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poverty, rural communities, sustainable development, water scarcity

1 | INTRODUCTION

The current water crisis is one of the most pressing global problems. The variability of the water cycle has increased due to climate change. Consequently, numerous regions across the world are currently facing severe droughts and brief periods of extreme precipitation whiplash, threatening the population's survival, socioeconomic development, food security, and healthy ecosystems. As climate change unfolds, an increased frequency and severity of droughts are anticipated, underscoring the significance of different factors contributing to water scarcity. Issues such as quality, quantity, and safe and equitable water access have become a matter of major concern for the welfare and prosperity of communities (Gerlak et al., 2018; Greve et al., 2018; Mekonnen & Hoekstra, 2016).

However, the most affected by this water scarcity are poor and vulnerable communities (UN-Water, 2019). Notably, people living in rural areas experience significantly lower levels of water access than their urban counterparts (WHO, 2017). This imbalance is exacerbated by the fact that the agricultural sector, which is the most substantial consumer of water, often leaves minimal reserves for human consumption within rural communities. Consequently, securing water for these communities, as well as for border economic activities and ecosystems, becomes essential for poverty reduction and the establishment of climate change mitigation strategies from natural disasters foreseen in the next decades (UN, 2018).

In Mexico, this pressing issue of water scarcity has manifested through an escalating water crisis, where drought and increased water consumption contribute to an inadequate supply for the main cities in the country (Martinez-Austria, 2020). The situation is even more distressing for the rural population, perpetuating disparities in water access and vulnerability to climate-induced challenges (Schneider, 2017).

The lack of or limited access to safe and sufficient water hinders economic development, which restricts the improvement of poverty alleviation and living conditions. Most rural communities in Mexico are marginalized, live in poverty, and have limited access to water (CEPAL, 2019; Laorden, 2018). These communities rely on ponds, wells, or rainstorms to meet their basic needs. Yet, these sources might be contaminated. Therefore, poor water quality and insufficient water can pose a health risk to people, causing water-borne diseases, such as diarrhea or typhoid. This situation imposes financial burdens through the costs of treating illness and losses incurred due to illness-related downtime (Li et al., 2019).

Furthermore, poor water quality can also pose a health risk to the ecosystems on which agricultural production relies, which in turn aggravates resident living conditions. Additionally, rural inhabitants face economic losses as they expend time and resources on fetching and treating water, as well as expect diminished agricultural productivity due to water scarcity (Hossain, 2018). Since agriculture is one of the most critical drivers of economic growth in these communities, the scarcity of water puts pressure on the availability of water for human consumption (Gomez et al., 2019), thereby rendering their economies reliant on water.

Moreover, the COVID-19 pandemic has highlighted the importance of water sanitation. Inadequate access to water may limit essential handwashing practices, while damaged sewer infrastructure exacerbates contact with wastewater. Unequal access to clean and sufficient water in rural communities results in a clear vulnerability to the pandemic's effects on health and the economy (Eichelberger et al., 2021; Stoler et al., 2020).

Insufficient water aggravates the living conditions of poor rural communities and limits socioeconomic development (Lara Cervantes, 2016). Therefore, water management in rural communities is essential for improving access to resources, increasing availability, and enhancing the socioeconomic conditions and overall quality of life of the inhabitants (CEPAL, 2020).

Managing water resources has become an increasingly complex challenge in a scenario where climate crisis, pollution, water demand, and food security are all intricately tied to this precious resource. This research seeks to emphasize the importance of water management in the rural communities of developing countries, where the use of water is the baseline for sustaining ecosystems, economies, biodiversity, and society. The lack of water in rural areas could be mitigated if water management planning is based on wide perspective information related to the social, cultural, political, economic, and environmental connotations of water scarcity (Gomez et al., 2019).

This paper aims to contribute to the body of knowledge on water scarcity and water security in Mexico, addressing the challenges associated with water access, especially for vulnerable rural communities. It further seeks to comprehend the complexities of evaluating water scarcity, while also examining the link between poverty, and water scarcity, and the influence of water governance and management.

2 | METHODS

This study is based on a comprehensive analysis and critical assessment of a diverse range of information sources. Following the review guidelines by Snyder (2019), an integrative literature review related to water resources in Mexico was conducted. It encompasses statistical data, scientific evaluations, policy and regulation documents, and governance mechanisms. The main motivation behind this study is to explore and address the context and challenges posed by water scarcity in Mexico, particularly its impact on rural marginalized communities in arid regions.

Considering the above, the following defined steps were undertaken in the development of this research: First, the investigation involved reviewing and synthesizing data and information regarding the situation of water resources in Mexico, describing the general context of water availability, quality, and characteristics of surface water and aquifers. This overview encompasses current patterns and trends in precipitation variations and the impacts of hydrometeorological events driven by climate change. Second, the exploration delved into the intricate factors contributing to water scarcity and the complexities surrounding the attainment of water security, such as equitable access to water and regulatory framework deficiencies in governance management, institutional coordination, access to information on water resources, and public participation. Third, the research examined the methodologies employed to scrutinize the water crisis in Mexico, analyzing the scope of the assessments, their limitations, and endeavors to encompass the complex social dimensions of water scarcity. Finally, there is an emphasis on shedding light on the context of rural marginalized communities, which bear the brunt of water scarcity in the arid regions of Mexico. This section integrates the information analyzed in the previous sections and includes social research perspectives that link the interaction between poverty and water scarcity. This study aims to draw a larger picture to understand how the physical water scarcity along with social, economic, and political factors hinder the overall well-being of these communities and their development. Potential strategies to alleviate this situation are also briefly revised.

3 | RESULTS AND DISCUSSION

3.1 | Water situation in Mexico

3.1.1 | Water resources

The complexity of Mexico's geography leads to a wide variety of climates throughout the territory. The northern and central zones, which cover two-thirds of the territory, have arid or semiarid ecosystems, with scarce annual precipitation averaging around 400 mm. Meanwhile, the southeastern region is humid, receiving precipitation that exceeds 2000 mm per year (CONAGUA, 2021).

Evaluations have pinpointed northern Mexico as one of the regions most adversely affected due to its arid landscapes (Aguilar Barajas & Ramírez Orozco, 2021; Gálvez, 2020; Mekonnen & Hoekstra, 2016; Montesillo Cedillo, 2017). More than half of Mexico's land (61%) has some degree of aridity, and human water demand is constantly increasing (Díaz-Padilla et al., 2011). In 2020, rainfall did not manage to fully supply all the dams in central and northern México (CONAGUA, 2020). The effects of this shortfall are still evident in 2023, with more than half of the most vital reservoirs operating at less than half of their capacity. In addition, the condition of most aquifers is critical (Gutiérrez-Ojeda & Escolero-Fuentes, 2020; Raynal-Villasenor, 2020; Villarreal, 2020).

Moreover, the distribution of water resources in Mexico does not align with the geographical distribution of the population or the economic productivity of different regions. In the central and northern regions, where rainfall is scarce, water availability is limited. Despite accounting for only 32% of the country's renewable water, these regions are home to 77% of the population and contribute 82% to the overall national economic output or gross domestic product (GDP) (Boltvinik & Damián, 2016; CONAGUA, 2021; INEGI, 2021).

In 2020, the annual per capita water availability in Mexico was 3663 m^3 (CONAGUA, 2021). However, this overall national figure does not consider the disparities in different regions due to the complex geographical features and diverse rainfall patterns across the country. Specifically, in the central and northern regions, the average annual water availability is approximately 1528 m^3 per person (CONAGUA, 2020). According to the Falkenmark index, areas with values under 1700 m^3 per person per year imply water stress. This implies that over two-thirds of the Mexican population resides in areas where the demand for water surpasses the available supply (Vanham et al., 2018).

Despite national estimates concealing regional water stress, the situation remains alarming. This is due to a substantial decline of nearly 30% in per capita water availability over the past three decades (CONAGUA, 2018). This decline is primarily attributed to fluctuations in precipitation patterns, population growth, and an increase in population concentration in urban areas (Montesillo Cedillo, 2017).

Across central and northern Mexico, precipitation patterns reveal a predominant monthly occurrence between June and September, accounting for approximately 68% of the total annual precipitation (CONAGUA, 2020). These regions experience prolonged periods of drought throughout most of the year, thereby exacerbating water scarcity. In some of these regions, most annual precipitation originates from cyclonic downpours associated with hurricane activity (Arámbula, 2005; Martinez-Austria, 2020). Furthermore, sudden downpours leading to flooding have detrimental effects, causing economic losses through infrastructure damage, lost crops, and even human casualties (Montesillo Cedillo, 2017; Villarreal, 2020).

In addition, it is imperative to account for distinct seasonal variations in rainfall distribution. As detailed in the 2022 Climate Report for Mexico (CONAGUA & SMN, 2022), these variations appear to have intensified over the past decade. From 2010 to 2020, the central and northern regions of Mexico experienced notable deficits in precipitation accumulation, contrasting notably with the patterns exhibited in the decades preceding this interval. This complex phenomenon is formally referred to as a “precipitation anomaly.”

It is of utmost importance to recognize the intricate relationship between precipitation patterns and climate change, as precipitation remains subject to the influence of global climate fluctuations. Mexico's central and northern regions are particularly vulnerable to the impacts of climate change, and rural communities in these regions are in a critical situation (Díaz-Padilla et al., 2011; Martinez-Austria, 2020). Climate change causes perturbations in precipitation dynamics, and projections predict that this variability will continue to intensify. Intense droughts are expected to become frequent in the arid region, whereas the southern territory may experience substantial floods. These phenomena impact water availability, which in turn negatively affects the supply and quality of water resources (IPCC, 2022).

Regarding water quality within the Mexican context, data provided by the 2020 Environmental Performance Index (EPI) reveal that nearly half of the country's surface water sources are contaminated, prominently attributed to fecal coliforms (CONAGUA, 2021; Wendling & Holt, 2020). This situation poses serious implications for public health. Moreover, approximately 8% of underground water sources exhibit instances of contamination, predominantly because of salinization or marine intrusion, but soil pollutants from agriculture and industrial activities can also affect water quality (Hoogesteger & Wester, 2018).

Underground water provides approximately 62% of Mexico's human water consumption (Gutiérrez-Ojeda & Escolero-Fuentes, 2020; Martinez-Austria, 2020; Raynal-Villasenor, 2020). Aquifers possess inherent characteristics that confer them with the advantage of an augmented reservoir capacity compared to surface water sources. In addition, they exhibit a heightened capacity for resisting contamination and enduring the effects of climate change. Moreover, they underpin 52% of the industrial water supply and 34% of agricultural production. Therefore, there is a great pressure on underground water resources, within arid and semiarid regions 17% of aquifers exhibit signs of overexploitation (CONAGUA, 2021). Overexploitation has been caused by high water extraction that surpasses the natural replenishment attributed to precipitation.

3.1.2 | Access to water and sanitation

The escalating water demand is also a matter of management and is closely linked to both population growth and increased economic activities, leading not only to water scarcity but also triggering political and social conflicts among the different users in the country (Arreguin-Cortes et al., 2019; De la Cruz Rock et al., 2009; López-Lambraño et al., 2020; Reis, 2017). In Mexico, deficiencies in the water supply and the provision of sanitation services have led to inequality in water access for the population (Hoogesteger & Wester, 2018; Montesillo Cedillo, 2017; Rolland & Vega Cárdenas, 2010). According to data from the National Institute of Statistics and Geography (INEGI, 2021), approximately 22 million Mexicans lack access to piped water in their homes. Moreover, an additional 10% of the population faces a complete lack of access to water. Populations residing where water extraction concessions exist are restricted to access to water, with concessions mainly granted to agricultural and mining industries. This affected population is concentrated in marginalized regions of the country, predominantly compromising rural inhabitants residing in arid areas. Limitations to water access not only perpetuate but also exacerbate social disparities (Dickson et al., 2016; Eichelberger et al., 2021).

The multifaceted issue of water access disparities is intricately intertwined with the challenges posed by inadequate infrastructure, which exacerbates the complexities of providing water to populations and perpetuates the ongoing degradation of water quality (Lara Cervantes, 2016; Reis, 2017). This issue is particularly prevalent in rural areas, where the most significant gaps exist in terms of drinking water and sanitation services (Jiménez-Sánchez, 2010). In addition, water sanitation infrastructure facilitates access to clean water and consequently influences socioeconomic conditions. In Mexico, only 57% of wastewater undergoes any form of treatment (CONAGUA, 2021). However, treatment facilities lack the technological capacity to remove emerging contaminants. The remaining wastewater (43%) is discharged untreated into surface water bodies, thereby exacerbating environmental issues.

In essence, water management institutions struggle to distribute this scarce resource equitably. Establishing the appropriate infrastructure and technology customized to the specific conditions of each region is imperative for enhancing water use and distribution, while also addressing the underlying social inequalities. Thus, water scarcity in Mexico is also influenced by social, institutional, economic, and political factors (Díaz-Padilla et al., 2011; Lara Cervantes, 2016; Torres Alonso, 2020).

3.1.3 | Framework for water regulation

Currently, the regulatory framework for water management in Mexico exhibits notable deficiencies, leading to various challenges, including human rights violations, unequal water distribution, and unsustainable practices (Embid & Martín, 2015; Lemos Figueroa et al., 2018). Regulatory frameworks profoundly influence crucial aspects of water governance, including public policies, management planning, pricing strategies, and the regulation of water subsidies. They establish the groundwork for water management planning to fulfill water-related policies, thereby shaping societal, economic, and environmental outcomes intertwined with water resources. Given the complex interplay of challenges posed by the water crisis, it is imperative to adopt an integrated and inclusive approach within the legal and regulatory frameworks for water management in Mexico (Pórcel & Pérez, 2017). An updated perspective on water management is essential to effectively achieve the overarching goal of ensuring universal access to water and a sustainable water future (UN-Water, 2019).

In Mexico, the National Water Law serves as the legal foundation for water resource management. Since 1992, this law has outlined conditions to ensure water sustainability and security, including the granting of water extraction concessions, regulations for water allocations, and discharge permits. It has granted the National Water Commission (CONAGUA by its acronym in Spanish) the responsibility of conserving national waters and their inherent assets for sustainable public administration and sufficient water supply for the population, spanning all productive sectors and encompassing environmental water requirements (Martínez Austria et al., 2019).

Moreover, underscoring its dedication to fundamental human rights and global initiatives, Mexico solidified its stance by enshrining the right to access water within its national constitution in 2012 (Wilder et al., 2020). The Mexican Constitution guarantees every person the right to accessible, safe, and affordable water for personal and domestic use, with the State being responsible for ensuring this right through established legal mechanisms (Ochoa-García & Rist, 2018). By that time, it was evident that the existing water regulatory framework outlined in the 1992 National Water Law was inadequate for addressing the complex issues related to the water crisis. As a response, the Congress was intended to dedicate a year to reviewing the water law to create a comprehensive set of regulations. This review of water law was expected to include an integrated set of regulations that not only recognize the human right to clean water and encompass other interconnected human rights. These included the right to a healthy environment, access to sufficient food, preservation of cultural identity, and assurance of good health (Casiano Flores, 2023; Lemos Figueroa et al., 2018).

The stipulated deadline has been exceeded by more than a decade, highlighting an omission and lack of compliance by the Mexican legislative authority. This situation highlights a dearth of commitment to meeting the country's international obligations concerning water management and access (García-Searcy et al., 2022). As a substantiation of this claim, the law fails to address the rights of indigenous peoples, allows private involvement in water and sanitation services, neglects the recognition of community systems, and grands CONAGUA extensive functions for water management, consequently resulting in restricted citizen involvement (Casiano Flores, 2023; Ochoa-García & Rist, 2018).

The current context often involves political decisions that prioritize economic growth, disregard considerations for the maximum sustainable limits within catchment areas, or uphold the safeguarding of ecosystems (Lara Cervantes, 2016). Water management policies predominantly focus on meeting the water requirements of urban areas and both industrial and agricultural activities. However, this approach can inadvertently sideline rural communities, raising concerns about equitable resource allocation and balanced environmental stewardship (Torres Alonso, 2020). Often, rural areas serve as the primary source of water, which is subsequently transported across significant distances to meet urban demand.

A district contrast emerges between management approaches to address the declining availability and quality of water surface and groundwater governance to alleviate the excessive exploitation of aquifers. In Mexico's regulatory framework, surface water management is designed on the basis of watershed factors, incorporating geographical and soil attributes along water pathways. Instead, municipalities managed aquifers resulting in a management approach rooted in a political administration. Regional diversity in aquifer management and dependance on municipal budgets have led to the neglect of acknowledging the intricate subterranean flow systems inherent to aquifers (Montesillo Cedillo, 2017; Pórcel & Pérez, 2017).

However, the management of surface water faces notable deficiencies. The central concern involves the pollution of surface water bodies due to industrial discharges, agricultural runoff, and untreated sewage discharge, which pose threats to water quality, ecosystem health, and inequitable access to clean water (Pórcel & Pérez, 2017; Sanchez Cohen et al., 2018). Moreover, significant water loss through leaks and inefficiencies within distribution systems results from deficient infrastructure and maintenance. These are compounded by the fragmented governance and regulatory frameworks, which create challenges in coordinating water management efforts among different agencies and jurisdictions. In addition, insufficient data collection and monitoring systems hinder the understanding of water availability and usage patterns, thus impeding informed decision-making in management strategies. These patterns often lead to conflicting priorities for water allocation and use.

Another concern regarding groundwater management is water concession administration. A large portion of the extracted groundwater volumes remains unmeasured, resulting in significant uncertainties concerning water availability, sustainability, and ecological impacts (Martínez-Austria & Vargas-Hidalgo, 2017). According to the monitoring and data collection system of the Public Registry of Water Rights (REPDA, 2020), approximately 71% of the concessions lack any form of measurement. Moreover, around 70% of concessions are held by a mere 7% of concessionaires, indicating the control over concessions by a minority of stakeholders. This situation has contributed to an unequal distribution of water resources and has led to escalating conflicts over water access, particularly in arid areas where aquifers are prone to overexploitation.

3.2 | Water security assessments

The concept of water security has emerged as a response to the pressing need to address and mitigate water scarcity situations by promoting sustainable and equitable management of water resources. Addressing water security is a global urgent necessity in policy agendas to achieve sustainable development. This worldwide consensus on water security constitutes a fundamental pillar of the United Nations agenda for 2030 (Hossain, 2018; Sadoff et al., 2020). Marked deficiencies in water security are attributed to a confluence of socioeconomic pressures, suboptimal institutional responses, and deficient water resource management (Gerlak et al., 2018). This approach prioritizes the regulation and administration of water resources within the framework of international policy directives (Damkjaer & Taylor, 2017). Despite the challenges posed by factors such as climate change and population growth, effectively managing water can significantly improve the water crisis. In addition, it involves the necessity to manage water-related risks with prevention, adaptation, or mitigation strategies to address the negative impacts of floods resulting from heavy rainfall and the scarcity of water caused by drought conditions (Grey & Sadoff, 2007). This is also relevant to the international agenda because of the interconnectedness of water resources and food security, highlighting the essential need to manage water to sustainably support food production (UN-Water, 2019).

With approximately two-thirds of Mexico's land characterized by arid and semiarid conditions; the country faces natural water scarcity. Moreover, these regions are vulnerable to significant deficits in water security (Arreguin-Cortes et al., 2020). Recent calculations of the Falkenmark Indicator in Mexico show that approximately 35.25 million people live in critical and extremely water-scarce conditions in the country's arid regions (CONAGUA, 2020).

A thorough analysis of water security implications, conducted by Raynal-Villasenor (2020), emphasizes that Mexico's categorization as a vulnerable nation to water security arises from its climatic, geographic, political, and social attributes related to water resources and the interactions of these factors. Additionally, Martínez Austria et al. (2019) noted the significant impact of agriculture on water security, as it consumes 70% of Mexico's water resources. This study revealed inefficiencies in industrial agricultural water usage, significant wastage, and notable reliance on overexploited aquifers. Other studies have carefully outlined the consequences of this situation, resulting in impoverishment, soil erosion, escalated climate-related risks, and diminished food and economic security (Arámbula, 2005; Barbier & Hochard, 2018; CEPAL et al., 2020; De la Cruz Rock et al., 2009; Gerlak et al., 2018; PNUD, 2006).

3.3 | Water scarcity assessments

Commonly used methods to measure water scarcity are calculated on the basis of the geographic and temporal mismatch between freshwater demand and availability. However, water scarcity is not exclusively tied to the physical constraints of water availability (Quinteiro et al., 2018; Rijsberman, 2006), and relying solely on this approach overlooks contextual realities in areas where precipitation and water flow might not be significantly reduced, but human factors still contribute to water scarcity. A more comprehensive and holistic definition of water scarcity encompasses various dimensions including social, economic, political, and cultural aspects that affect how water is accessed, distributed, and managed in various contexts (Damkjaer & Taylor, 2017; Hossain, 2018; Vanham et al., 2018). Because of its complexity, there is no agreed-upon definition or standardized method for measuring water scarcity. Consequently, various assessments capture distinct aspects of water scarcity. By outlining the scope and limitations of each analysis, the assessments contribute pieces to the larger puzzle and offer a comprehensive view. Thus, measurements can take the form of physical assessments or be framed in terms of social or economic implications (Guppy et al., 2019).

Water scarcity assessments have primarily evaluated the progress toward reducing water scarcity and identified future occurrences of water scarcity (Damkjaer & Taylor, 2017). Findings from diverse evaluations and metrics provide a baseline for developing sustainable water management strategies to improve water access without disrupting ecosystem water cycles. This section examines the results of diverse studies conducted in Mexico's arid regions. The relevant results are organized on the basis of the dimensions of water scarcity assessed: physical, social, or economic.

3.3.1 | Physical water scarcity

The Falkenmark Indicator or water stress index (WSI) is one of the most widely used methods for assessing the balance between water supply and demand within a region or country (Damkjaer & Taylor, 2017). It serves as an approximate measure to gauge the pressure on water resources. As previously mentioned, estimations of the WSI in Mexico have revealed that half of the population living in the central and northern regions of the country lacks sufficient renewable freshwater (CONAGUA, 2021).

However, this approach neglects factors associated with water supply and demand, such as culture, lifestyle, climate, and water resource accessibility (Rijsberman, 2006; White, 2014). In addition, it does not consider variations in water use and demand within a region, particularly in the context of assessing heterogeneous areas where available water faces pressure from agricultural production or densely populated urban centers. Consequently, arguments have arisen that the WSI might underestimate the impacts on smaller populations and fail to effectively compare water stress between regions (Damkjaer & Taylor, 2017). This is relevant because, in Mexico, similar to global trends, the population is increasingly concentrated in urban areas, and agriculture accounts for approximately 70% of freshwater extractions (CONAGUA, 2021; UN, 2018).

Furthermore, the demand for water is increasing because of population growth and the rising need for food production. This issue is exacerbated by the climate change-induced alterations in precipitation patterns in central and northern Mexico. From this perspective, several evaluations have examined the physical scarcity of water resources required for food production and human well-being. Thus, Rosa et al. (2020) conducted a monthly agrohydrological analysis of water scarcity and found that the water crisis constricted global food production. Moreover, this study highlights that regions such as the high plains of the southern United States and northern Mexico could only meet current agricultural water demands through the sustainable use of water resources.

In addition, Sanchez Cohen et al. (2018) analyzed food production despite water constraints due to the impacts of El Niño climate phenomena using a standardized precipitation index. The findings indicated that irrigation systems in northern Mexico could withstand future predictions of water scarcity, even with worsening El Niño impacts. This study demonstrated that even with restricted irrigation water, crops can be maintained with lower water demands through increased institutional and financial support for hydrological irrigation systems. Furthermore, in a case study conducted in the Guadalupe Basin, López-Lambraño et al. (2020) assessed the challenges for wine production under scenarios of severe aridity conditions and high water demand for both human consumption and crop irrigation. This study demonstrated the feasibility and effectiveness of rainwater harvesting as a sustainable strategy for ensuring access to water resources during months of limited rainfall.

A third approach is to quantify the degree of aridity or dryness in a particular region using the Aridity Index (AI). It represents the balance between available water resources (precipitation) and the potential water loss from the soil and vegetation due to evaporation and transpiration, collectively known as potential evapotranspiration (PET) (UNEP, 1992). AI categorizes regions into different levels of aridity. In Mexico, estimates reveal that 1% of the territory is hyper-arid, 27% is arid, and 35% falls within semiarid zones (Díaz-Padilla et al., 2011). However, limitations in aridity measurements have been prevalent in developing countries due to the lack of measured PET data and challenges with accurate PET estimations (Sahin, 2012). A more comprehensive evaluation of aridity aims to overcome these limitations through the application of geostatistical interpolation models (De Jesus Correa-Islas et al., 2023). This study predicted future aridity scenarios in northern Mexico that may worsen the current situation, potentially leading to a gradual decline in humidity and environmental resilience.

Until now, water scarcity indices have predominantly focused on describing the shortage of water resources in terms of meeting water demand. However, water scarcity extends beyond physical or environmental constraints and encompasses social, economic, political, and cultural dimensions that impact water access, distribution, and management (Gálvez, 2020). Despite this, quantifying water scarcity resulting from diverse social factors presents considerably greater complexity (Quinteiro et al., 2018).

3.3.2 | Socioeconomic water scarcity assessments

One of the approaches used to quantify the socioeconomic implications of water scarcity is the Global Water Security Index (GWSI), which measures water security in line with Goal 6 of the 17 Sustainable Development Goals established by the United Nations (United Nations, 2015). The GWSI integrates physical and socioeconomic indicators of water security, comprising four criteria: water availability, accessibility, and quality, along with safety and management (Gain et al., 2016). Although the index is primarily applied at a global scale, assessments at various scales within Mexico have been conducted (Arreguin-Cortes et al., 2019, 2020). However, the authors recognized challenges in applying this methodology due to difficulties in accessing data concerning water availability and water quality monitoring, along with the complexity of integrating elements such as water governance and institutional coordination (effectiveness). Because standardized data might not be accessible for every region, making comparisons is unfeasible (Brown & Matlock, 2011).

To provide a broader understanding of water scarcity, the International Water Management Institute (IWMI) proposed a method that addresses limitations by including water infrastructure, recycled water, and adaptive capacity (Damkjaer & Taylor, 2017). This method categorizes countries as economically water scarce if they are unable to meet future demand without investing in water infrastructure, that is, economic water scarcity, and physically water scarce if they are unable to meet demand even with investment, that is, physical scarcity. In Mexico, the implementation of this methodology has pinpointed the central and northern regions as water physical scarce, while the southeastern region faces economic scarcity. However, these estimates should be approached with caution because this approach overlooks people's adaptive capacity and economic resources to cope with declining water availability (Torres Alonso, 2020).

Another approach is the Water Poverty Index (WPI), which employs a multidimensional methodology encompassing five key components: available water resources, water access, water management capacity, water use for domestic, food, and production purposes, and environmental concerns (Sullivan et al., 2006). These components are integrated into a single measure. However, because of the complexity involved in integrating extensive and varied data, its applicability is better suited for analyzing smaller-scale areas, particularly within vulnerable communities. Some evaluations have implemented this approach in Mexico, at both local and national levels, highlighting the involvement of inhabitants in marginalized areas in participatory water management (Camberos, 2021; López-Álvarez et al., 2019; Wurtz et al., 2019). However, there are still limitations in effectively incorporating information related to the political and social factors causing water scarcity (Anju et al., 2017).

From an economic perspective, water scarcity involves changes in consumption patterns and economic costs for adaptation. Additionally, water scarcity impacts various economic sectors, involving interactions between consumers, producers, and different economic activities (Garfì & Ferrer-Martí, 2011; Lara Cervantes, 2016). Although the aforementioned methods strive to incorporate adaptation costs related to water scarcity primarily focused on agriculture or infrastructure (Eichelberger et al., 2021; López-Lambraño et al., 2020; Rosa et al., 2020; Sanchez Cohen et al., 2018), the hydro-economic model has been employed to examine shifts occurring in distinct economic sectors (Dolan et al., 2021).

The challenge of evaluating water scarcity and its impact on communities persists due to the lack of consensus regarding the most accurate assessment methodology for the social, economic, and environmental conditions specific to each region (Hossain, 2018; Torres Alonso, 2020). Developing a precise evaluation requires considering the influence of socioeconomic factors on water availability conditions. While some authors argue that attempting to measure socioeconomic indicators can prove exceedingly complex and potentially undermine the accuracy of water scarcity assessments, others advocate confining such assessments to physical descriptions of the environment (Damkjaer & Taylor, 2017; Vanham et al., 2018).

Other studies have proposed differing methodologies, ranging from using multivariate techniques to employing indicators compiled from systematic reviews (Dickson et al., 2016; Domínguez et al., 2019; Garfi & Ferrer-Martí, 2011). However, effectively integrating social, economic, and environmental factors into assessment models continues to pose a notable challenge, because of an incomplete understanding of the interactions and criteria for quantifying social water scarcity. Recent approaches have incorporated diverse sources of data and social studies to target management strategies and interventions aimed at assisting vulnerable communities in water management. The following section addresses qualitative studies that examine, from a social perspective, issues such as deficiencies in water planning and management, institutional incapacity to provide water services, unsustainable economic policies, disparities in power relations, inequality, and poverty, all of which contribute to the exacerbation of water scarcity.

3.4 | Water crisis correlation with poverty

People facing poverty often encounter impediments to their economic and social progress, which are further exacerbated by their limited access to natural resources (UN, 2018). Water scarcity constrains the capacity to sustain life, well-being, and socioeconomic progress. Since the beginning of the millennium, recognizing access to safe water as an essential human right has been a fundamental priority on the United Nations' agenda (UHCHR & WHO, 2010), which has encouraged governments to enhance their efforts to satisfy human needs and meet the UN's Sustainable Development Goals (UN, 2018).

Limited access to safe water is both a contributing factor to poverty and a consequence thereof (Serebrisky et al., 2018). Water is a fundamental resource for daily necessities such as drinking, food preparation, and sanitation. Beyond these immediate necessities, water is essential for sustaining agriculture production, food systems and supporting other vital productive activities. However, marginalized and impoverished communities, which are often prevalent in rural areas, bear the brunt of water scarcity, as poverty compounds the challenges of securing sufficient water for daily needs and family farming (Hemson et al., 2013; Lara Cervantes, 2016). Thereby, these communities are compelled to grapple with the dual struggle of poverty and water scarcity, creating a cycle of vulnerability that is difficult to break (Boltvinik & Damián, 2016; UN, 2018).

Several authors agree that addressing the water crisis in the rural sector is a priority for achieving socioeconomic development and implementing strategies to adapt to climate change (Garfi & Ferrer-Martí, 2011; Villada-Canela et al., 2019). Studies have discussed the pivotal role of water management improvements in promoting sustainable development and alleviating poverty (Dickson et al., 2016; Lemos Figueroa et al., 2018). However, attempting to reduce rural water poverty in Mexico is a complex problem. This involves considering various factors, including physical water scarcity, contamination, and the impacts of climate change on the water cycle, but most importantly, the intricate aspects of water management, land-use planning, and regulations framework (Martínez Austria et al., 2019; Raynal-Villasenor, 2020).

Rural communities hold significant importance within Mexico's economy, serving as the sector that supplies food and natural resources, especially water resources, to sustain the survival of large urban areas (Díaz-Padilla et al., 2011; Martínez Austria et al., 2019). Despite comprising only 23% of the total population, the rural sector contends with a substantial poverty rate of 55%, and an estimated 5.2 million individuals endure the hardships of extreme poverty (CONEVAL, 2018; INEGI, 2015). The absence of adequate water services faced by this population has had a detrimental effect on their overall progress, hindering their social development. This water scarcity creates a domino effect that impacts various aspects of rural life, such as health education, livelihoods, and overall resilience (CEPAL, 2019; Martínez-Carrasco, 2014; Stoler et al., 2020).

In addition, rural communities, especially those in Mexico's driest regions, are scattered in isolated locations (INEGI, 2021). This geographic dispersion poses challenges for public institutions in terms of providing quality public services, resulting in increased costs for government investments. In such cases, rural inhabitants must bear the costs associated with obtaining water from distant sources or purchasing it from private providers (Gomez et al., 2019; López-Morales & Duchin, 2015). For rural communities already grappling with poverty, these escalating costs create a detrimental ripple effect. Individuals and families with limited financial resources find it even more challenging to afford the fundamental necessities required for their sustenance and livelihoods, such as education and healthcare (Arámbula, 2005; Reis, 2017; Stoler et al., 2020).

Therefore, water serves as an economic commodity, and its valuation reflects its scarcity and the investment required for allocation and treatment (Soares, 2021; Staddon & Scott, 2018; Wilder et al., 2020). In terms of allocation, there is a significant disparity in access to water services between urban and rural areas. In Mexico, as in other developing countries, urban areas have a higher coverage percentage due to higher population density, making supply more affordable and accessible. Conversely, providing water services to remote areas where the rural population inhabits is more expensive in terms of government investment in infrastructure. The high cost associated with water supply in rural areas is often justified by the underrepresentation of the rural population. Over 70% of Mexico's population, while the rest of the population lives in communities with less than 2500 inhabitants (criterion used for rural classification). Consequently, public investment exhibits a bias toward urban areas (Fernández et al., 2022).

The rural population's constraints to access water services are compounded by the higher expense of accessing water resources. Therefore, the income of the rural population is a crucial factor in accessing water supplies in remote areas. The water supply of these populations predominantly depends on natural sources of water, such as aquifers and springs (García-Searcy et al., 2022). Inhabitants of these rural communities must bear the costs of transporting water. It is often the community that uses its budget to build or repair infrastructure such as wells or cisterns (Soares, 2021). Water quality derived from these sources remains generally uncertain throughout all localities, and institutional diagnosis remains predominantly absent. While some communities place trust in the water quality of their sources, others show skepticism and opt to purchase bottled water (Faviel Cortez et al., 2019; Gomez et al., 2019; Stoler et al., 2020). This perpetuates a cycle of deprivation and restricts opportunities for economic improvement and social mobility.

Water scarcity in Mexico's arid regions results from a complex mix of factors, including physical water shortages, however, water governance and water management are considered to play a greater role (Reis, 2017; Wilder et al., 2020). As previously outlined, water resource-related public policies in Mexico still operate within an insufficient legal framework (Luiselli Fernández, 2018). For instance, access inequity and social conflicts arise from infrastructure projects such as dams or aqueducts (McCulligh & Tetreault, 2017). Numerous studies have revolved around discussions concerning the commercialization of water and the privation of water-related-rights, resources, and infrastructure that were previously within the public or common domain (Gálvez, 2020; Martínez-Austria & Vargas-Hidalgo, 2017). Other studies highlight the lack of attention to improving access and water supply in rural populations is due to water not being managed as a public good. Instead, corporate interests and privileged stakeholders create an unequal distribution and monopolization of water, fostering resource scarceness (Kručková & Turner, 2017; Rolland & Vega Cárdenas, 2010; Torres Alonso, 2020). Despite the concerns about water availability, the major problem is inequality as certain social groups are excluded from access to water.

In arid regions, water stress worsens water scarcity for rural communities, especially when industrial farming has more financial resources and infrastructure. This can reduce water availability for local farmers, thereby affecting their productivity, livelihoods, and basic needs (Díaz-Padilla et al., 2011; Dickson et al., 2016; Martínez Austria et al., 2019). Such challenges are exacerbated by land degradation and aridity, which affect the role of natural vegetation in replenishing aquifers, rivers, and soil health.

Furthermore, local-scale farming is the predominant form of agriculture in rural communities. These communities are substantially reliant on agriculture and cattle-raising for their livelihoods, making water scarcity due to droughts a critical factor influencing their living conditions and income sources (CEPAL, 2020). However, industrial farming water needs can strain local resources. A significant portion of farmland depends on rainwater, but the lack of proper infrastructure and water management causes approximately 60% of this water to go to waste (CONAGUA, 2020). This problem intensifies with competition from industrial agriculture companies for water resources. Industrial agriculture, which is characterized by large-scale farming operations has substantial water demands for irrigation (Martínez Austria et al., 2019).

To address the rising demand for food without expanding the cultivated areas and undermining farmer livelihoods, agricultural practices require improved irrigation and sustainable water management practices (CEPAL, 2019; Pórcel &

Pérez, 2017; Rosa et al., 2020; Schneider, 2017). Evaluations of the major irrigated croplands in the arid regions of Mexico by Rosa et al. (2020) proposed the concept of "agricultural economic water scarcity" to enhance the sustainable irrigation of water-scarce croplands, arguing that in most cases, the lack of irrigation in arid Mexico was due to limited institutional and economic capacity rather than hydrologic constraints. In particular, for small-scale agriculture in arid regions of Mexico, the current water availability could be improved by introducing appropriate technologies, water reuse, training, and greater control of irrigation allocations (Martínez Austria et al., 2019; Velasco-Muñoz et al., 2019).

In addition, the vulnerability of Mexico to climate change is influenced by its geographical features, whereas economic conditions exacerbate the impacts of extreme hydrometeorological events (Arceo-Gomez et al., 2020). The livelihoods of millions are at risk from floods or droughts, particularly in the arid areas in northern Mexico, where consistent patterns of drought exceed projections (Galvez et al., 2020). Recent studies have focused on understanding the impacts of droughts on rural communities and their adaptive capacity under economic constraints. The findings provide compelling evidence that droughts detrimentally affect the well-being of rural households, leading to reduced earnings and an increase of nearly five percentage points in the likelihood of experiencing poverty following a drought, compared with their unaffected counterparts (Arceo-Gómez et al., 2020).

As climate change intensifies, an increase in the frequency and severity of droughts is expected, highlighting the need to address the requirements of rural communities and comprehend the elements bolstering their adaptive capacity. Nonetheless, rural communities demonstrate diverse levels of resilience despite water scarcity and climate change impacts (McCulligh & Tetreault, 2017). The adaptability and ability to withstand these challenges are determined by factors such as geographic location, socioeconomic conditions, resource accessibility, and existing infrastructure (Laorden, 2018). While certain rural communities have developed innovative strategies to cope with water scarcity and climate-induced pressures, others may struggle due to limited resources, insufficient support systems, and vulnerabilities stemming from poverty and isolation (Lara Cervantes, 2016).

In these cases, communities with better organization, cooperation, participation, and higher economic resources tend to improve their access to water and adaptive capacity. Although these cooperative efforts are important, they require continuous external support, including funding, technical advice, and democratic participation. This support must come from public entities to maintain water quality and long-term coverage. However, in Mexico, institutional support falls short in providing such assistance (Hutchings et al., 2015; Koff et al., 2022; Pinilla-Rodriguez & Torres-Sanchez, 2019).

The regulatory framework in Mexico has contributed to the uneven distribution of economic resources among public institutions responsible for upholding the right to equitable water access (Serebrisky et al., 2018). Few efforts have been made to enhance rural infrastructure and implement irrigation programs for small-scale agriculture (Luiselli Fernández, 2018; Sanchez Cohen et al., 2018). Therefore, there remains a pressing need for the implementation of cost-effective technologies and comprehensive, multi-sectorial rural development policies to alleviate poverty and enhance the well-being of the rural population (Lemos et al., 2020).

Currently, researchers underscore that even in instances where laws aim to eliminate water privatization, achieving equity in access to water through public water management remains a significant hurdle (Embid & Martín, 2015; Martínez-Austria & Vargas-Hidalgo, 2017; Pórcel & Pérez, 2017). Incorporation of stakeholders in water management has faced obstacles due to varying levels of information and influence, institutional shortcomings, limited resources for stakeholder engagement, and a lack of motivation (Villada-Canela et al., 2019). Hence, a refinement of existing participatory mechanisms is imperative to ensure that water management strategies are holistic, sustainable, and aligned with the needs and priorities of the people directly affected by water scarcity and socioeconomic challenges.

In this context of stakeholders involved in participatory mechanisms, research has highlighted that women's active engagement in water management holds the potential to significantly reshape and enhance the sustainability of water resource utilization in rural communities. Women hold a central cultural position in providing water, preparing food, and maintaining hygiene. Their everyday practices, shaped by experience and expertise, effectively manage water resources (Hemson et al., 2013). Women's water management in rural communities has diminished the adverse impacts of water scarcity by water reuse for multiple purposes. Fielmua and Mwingyine (2018) found significant potential for achieving sustainable development goals by investing in multiple-use water services to empower women to actively engage in multiple income streams and enhance water access. Female participation in public water management is crucial to the sustainability of services, especially in rural areas where gender roles are generally constrained. Consequently, to develop effective water policies, it is imperative that participatory schemes integrate gender perspectives to encompass women responsible for rural water supplies, aligning with the recurring emphasis in numerous studies on the significance of women's involvement in water management planning and policies (García et al., 2014; Gómez Colín et al., 2017; Jiménez-Sánchez, 2010; Silva Rodríguez de San Miguel, 2018).

Furthermore, community water and sanitation systems (SCAS) have emerged as a viable solution in areas where municipal water authorities lack universal coverage. The SCAS mainly serves rural localities to promote civic engagement, facilitate collaborative water management, enhance resilience against climate and health challenges, and foster a platform for local governance and capacity building. These systems hold particular significance for ingenious communities because of their preservation of cultural practices in natural resource management and traditional governance over territories (Aguilar Amilpa, 2011; Galindo-Escamilla & Palerm-Viqueira, 2007; Ibarra Madrigal et al., 2020; López García et al., 2017; Matus Ruiz et al., 2023; Ramos-escobedo et al., 2019; Sandoval-Moreno & Günther, 2013; Silva Rivera et al., 2012).

However, these SCAS often face a lack of formal legal recognition, leading to their exclusion from state-provided financial resources and opportunities for skills development. This absence of recognition hampers their potential to fulfill Goal 6 of the SDG. Nevertheless, specific instances can be found in some rural localities in Mexico where private sector entities or NGOs assist communities in upholding, respecting, and ensuring water-related rights, while aligning with the goals set forth in the 2030 Agenda. These projects implement sustainable technologies such as water harvesting systems (Hossain, 2018). Thus, it is crucial to establish legal certainty for rural communities, strengthen their organizational and operational capabilities, and appropriately acknowledge their essential role in water management and provision (Villada-Canela et al., 2019).

Despite the recognition that countries must adapt their water policies for sustainable management, Mexico, like many other developing nations, grapples with the transition from policy to action (Embid & Martín, 2015). Many studies have argued that despite the geographical characteristics of Mexico, management is responsible for water scarcity (Gálvez, 2020; Martínez-Austria & Vargas-Hidalgo, 2017; Montesillo Cedillo, 2017; Torres Alonso, 2020). Equally vital is the existence of political will, which is characterized by shared recognition of the water scarcity crisis, and heightened awareness among stakeholders. This is imperative to facilitate the implementation of a novel regulatory framework designed to improve water availability, quality, and access. Water management should make water sufficient for human activities and accessible equitably across various social and economic sectors. In addition, it is important that the management involves the ecosystem conservation. Ecosystems provide health and functionality to watersheds, rivers and aquifers by enhancing water availability, regulating water flow and improving water quality.

4 | CONCLUSIONS

Water scarcity in Mexico results from the interplay among its diverse geography, changing climate patterns, and human interventions. This challenge is particularly pronounced in the central and northern regions of the country, where arid and semiarid climates prevail, leading to heightened water scarcity concerns. The exacerbating impact of climate change over recent years has escalated the frequency and severity of droughts, significantly affecting water availability and the socioeconomic fabric of the communities inhabiting these regions. The vulnerability of these regions is underscored by a combination of factors, including the overexploitation of aquifers, distribution network deficiencies, pollution, and inadequacies in water management governance. The situation is exacerbated by the concentration of more than two-thirds of Mexico's population within these regions. The distribution of the population, coupled with high-density urbanization trends, plays a pivotal role in determining the dynamics of water demand and supply, along with competition and conflicts over the use and access to water.

The challenges faced by rural communities in these arid regions are even more formidable. Struggling against the dual challenges of poverty and water scarcity, these marginalized areas often grapple with inadequate water supply and sanitation services. This not only perpetuates disparities in water access but also heightens their vulnerability to climate-induced adversities. Consequently, rural communities find themselves in a vicious cycle where water scarcity exacerbates poverty, affecting crucial aspects of life, including health, education, livelihoods, and overall resilience. Addressing the water scarcity issue for these communities is imperative to ensure not only their development but also the stability of the broader social and ecological framework for ensuring sustained national water and food security.

The urgency to assess the worldwide water crisis has led to the development of different methodologies aimed at identifying the causes and contributing to finding solutions. Commonly used methods to measure water scarcity have predominantly focused on describing the shortage of water resources in terms of meeting water demand. However, creating comprehensive water scarcity models involves numerous challenges and limitations, such as limited data availability and insufficient monitoring and measurement of water resources, particularly in remote or less-developed regions. Furthermore, it is essential to recognize that water scarcity is not determined only by the physical constraints of water availability. Depending solely on this perspective might overlook contextual realities where precipitation and water flow remain relatively unaffected, yet social and economic factors profoundly influence water access and distribution. Achieving a holistic evaluation requires acknowledging the role of socioeconomic factors in shaping water availability conditions.

While various proposals have attempted to incorporate the distinct social, economic, and environmental characteristics of each region, the challenge of assessing water scarcity and its societal impact persists. The absence of consensus on the most accurate assessment methodology complicates the process. The intricacies of measuring socioeconomic indicators are underscored by the intricate interactions and criteria for quantifying social water scarcity. To overcome these complexities, recent approaches endeavor to integrate diverse sources of data and qualitative studies, examining social perspectives that encompass water planning and management deficiencies, institutional shortcomings in providing water services, unsustainable economic policies, power disparities, inequality, and poverty.

Through these assessments, a more comprehensive understanding of the water scarcity puzzle has emerged. There is a general agreement that promoting sustainable and equitable management of water resources can diminish the solution to the water crisis. The information and insights gained from the assessments can be used by policymakers, private institutions, communities, and other stakeholders to design and implement strategies that are better aligned with the complex realities of water resources. Water management should make water sufficient for human activities and accessible equitably across various social and economic sectors, without disrupting ecosystem water requirements. Integrating informed policies, effective management, and collaborative efforts are crucial to securing a prosperous and sustainable future for Mexico's water resources.

Addressing water scarcity in Mexico requires a comprehensive strategy that encompasses several key initiatives. A crucial initial step involves developing and implementing a long-term integrated management plan that considers the quantity and quality aspects of water resources. The national water policy must be revamped to enhance efficiency, decentralize water rights, and establish effective coordination between regional governments. Tariff policies need reevaluation to better reflect socioeconomic status, and water allocations should be systematically planned, potentially incorporating targeted subsidies to ensure access for the marginalized population. Focus should be directed toward mitigating the overexploitation of aquifers by implementing policies that encourage the reduction of water usage in agriculture and the adoption of sustainable practices. Urban planning improvements, particularly in densely populated areas, should focus on efficient sewage networks, wastewater treatment facilities, and pollution mitigation. It is evident that addressing water scarcity requires a holistic approach, in which policies should strike a balance between economic growth, natural resource management, environmental conservation, and poverty alleviation. Moreover, policies require thorough evaluation, considering the diverse geographical, economic, and social characteristics of different regions in Mexico.

The necessity of a comprehensive and all-encompassing approach to water management is evident, encompassing engagement with local communities, fostering collaboration across diverse sectors, and considering the unique conditions prevalent in rural regions. Additionally, the decentralization of water management jurisdiction, the integration of diverse financial schemes for water infrastructure, the incorporation of sustainable management strategies within water regulatory frameworks, and the recognition of the vital contributions made by rural communities in water management and provision constitute essential approaches for addressing the underlying factors contributing to water scarcity in Mexico. Further research and development efforts are imperative to explore innovative solutions. A multifaceted approach tailored to the diverse characteristics of different regions holds promise for alleviating water scarcity in Mexico and promoting sustainable water management practices.

AUTHOR CONTRIBUTIONS

Silvana Pacheco-Treviño: Formal analysis (equal); investigation (equal); writing – original draft (equal). **Mario Guadalupe Francisco Manzano-Camarillo:** Conceptualization (equal); resources (equal); supervision (equal); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article references. Other data supporting the findings of this study are available from the corresponding author on request.

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