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Green Infrastructure Solutions to the Environmental Impacts on Water Scarcity in Mexico

The water crisis in Mexico has many causes and effects, especially in the environmental sector. Almost half of Mexico experienced moderate to severe drought in 2023, and up to 80% of Mexicans will live in high water stress by 2050 (Beltrán, 2024). Climate change predictions conducted by Jessica Bravo-Cadena and other researchers for the *International Journal of Environmental Research and Public Health* suggest that drought severity could increase by as much as 200% by 2080, and 6.5% of the land area was predicted to have a 100% decrease in water availability in their study area of southern-central Mexico (Bravo-Cadena, 2021). Mexico has a population of about 131 million, and the number of municipalities that have a greater water demand than what is available is expected to rise from 27% to 39% by 2050 (Bravo-Cadena, 2021). With reduced water availability, heavily water dependent industries such as agriculture suffer. According to historian David Burnstein, Mexico is characterized by "vast natural resources," "a wide array of climatic conditions," and "biological diversity." These aspects of Mexico are threatened by water scarcity, which is driven by the overexploitation and destruction of those natural resources along with poor water quality from pollution. Considering the possible ways to mitigate these issues, improving water treatment capabilities through green infrastructure is one of the most critical solutions that should be implemented.

Overexploitation and Destruction of Habitats

Overexploitation of natural resources and destruction of water-sustaining ecosystems are major factors contributing to water scarcity in Mexico. According to independent journalist Amigzaday López Beltrán, habitats such as mesophyll forests, coffee plantations, and forested highlands fill essential roles in recharging natural water stores and the water cycle (Beltrán, 2024). When these ecosystems are destroyed, mainly by urban or agricultural development, it can cause increased runoff and decreased infiltration to aquifers, reducing natural water stores. Research conducted by Carlos A. López-Morales for the University of Mexico's Center for Demographic, Urban and Environmental Studies supports this, as they have shown that areas of high vegetation correspond to areas with high ground-water recharge capacities. Additionally, as continued habitat destruction decreases water availability, demand continues to rise; the water extraction rates in central Mexican aquifers were found to be 1.8 to 4.3 times higher than the natural recharge rate (López-Morales, 2017). This overuse of groundwater resources further diminishes recharge rates by destroying water-holding ecosystems, worsening the situation. Urban development also destroys natural environments, resulting in reduced water availability, according to a study conducted by Carlos Alfredo Bigurra-Alzati and other researchers for the Autonomous University of the State of Hidalgo. Their research found that as naturally water-storing environments are paved over with nonpermeable and heat absorbing material, it creates urban heat islands where temperatures rise very quickly during the day. Nonpermeable concrete increases stormwater runoff and flooding as water is unable to soak into the ground to cool surface temperatures, while concrete also absorbs heat, creating unnaturally hot areas in urban zones (Bigurra-Alzati, 2020). These high temperatures both increase water demand and reduce water availability, contributing to water scarcity.

One proposed solution to the over-extraction of groundwater, described by Rolando E. Díaz-Caravantes and Christopher A. Scott in their geographical analysis of Mexican water resources, is to cap groundwater extraction levels to leave behind enough water for the ecosystem to remain undamaged (Díaz-Caravantes, 2010). However, this would make it difficult to meet the rising water demand. In order to solve this

problem, green infrastructure can be utilized to reuse water, decreasing the need for groundwater extraction. Examples of this type of infrastructure include artificially constructed wetlands, lagoons, ponds, and other surface water bodies, typically built in urban or suburban zones. Constructed wetlands in particular offer an excellent solution to both increase water treatment capacity and restore the natural habitats destroyed by urban expansion. A study by Alexandros I. Stefanakis, published in the peer reviewed journal *Sustainability*, states that artificial wetlands can create new ecosystems or restore degraded ones as wildlife species migrate to areas with water and vegetation (Stefanakis, 2019). These "kidneys of the landscape" recreate the water-sustaining conditions found in natural wetlands, according to a peer reviewed paper on constructed wetlands from the journal *Critical Reviews in Environmental Science and Technology*, written by Piyush Malaviya and Asha Singh. This approach has been described by Carlos A. López-Morales in *Resources, Conservation, and Recycling*, a peer reviewed scholarly journal. Examining the region of the Mexico Valley Basin, which contains Mexico City, López-Morales found that while over-exploited aquifers currently produce enough to meet demands, only 10% of wastewater in the region is treated (López-Morales, 2019). In order to reduce the need for groundwater extraction to a non-exploitive level while still meeting the demand, the capacity for wastewater treatment and reuse must increase by 4 to 6 times, depending on how well domestic leaks can be managed (López-Morales, 2019). Reused wastewater could make up 41-48% of annual water usage by doing so (López-Morales, 2019). The implementation of green infrastructure is needed to achieve this treatment capacity.

Pollution in Water Sources

Environmental pollution also contributes to water scarcity as water quality is worsened. Nearly half of Mexico's surface water sources are contaminated and about 8% of underground water sources are contaminated, according to the 2020 Environmental Performance Index. An example of contamination reducing water availability is agricultural pollution's increased impact on rural communities. According to TheGlobalEconomy.com, a website for economic data run by Ph.D. economists Neven Valev and Menna Bizuneh, about 50% of Mexico's land area is dedicated to agriculture, and rural communities are very dependent on farming (Valev, 2021). However, a case study supported by the National Council for Science and Technology in Mexico and conducted by Monika Moeder, Otoniel Carranza-Diaz, and other researchers found that agricultural runoff deposits pesticides, artificial sweeteners, pharmaceutical residue, and livestock feces, which breed Ebola and other fecal coliforms, into surface water (Moeder, 2017). As rural communities have limited access to water purification facilities, these pollutants make rivers and springs, sometimes their only sources of water, unsafe to drink. In urban areas, stormwater can quickly flood areas that are covered in impervious concrete surfaces, as stated in a review published in the *Sustainability* journal and authored by Nash Jett Reyes and other researchers. Stormwater flow then causes heavy urban runoff, carrying toxic pollutants that contribute to water pollution and threaten human health (Reyes, 2023). Malaviya and Singh's paper goes on to state that urban runoff that flows into drainage control systems is later discharged into surface water bodies, concentrating the pollution from a large area to a single point (Malaviya, 2012). This heavily damages aquatic environments by eroding banks and river beds and killing aquatic life (Malaviya, 2012). The effects of untreated wastewater pollution on water quality have been found in several studies. According to a literature review of water scarcity assessments by Silvana Pacheco-Treviño, only 57% of all wastewater, including raw sewage, is treated while the rest is usually dumped directly into surface water sources (Pacheco‑Treviño, 2024). Along with this, the aquifers which supply most of central Mexico's water have been found to be contaminated by leaks in wastewater drainage (López-Morales, 2017). A report by José de Jesús Návar Cháidez, a professor at the Interdisciplinary Research Center for Comprehensive Regional Development, found that untreated industrial waste containing heavy metals and other chemicals is discharged into surface water as well. He reported that water quality studies have found unsafe levels of contaminants in major tributaries, as found in 1996 studies on the Rio San Juan and Rio Santa Catarina tributaries. The studies showed that 18% of the stream water samples that were analyzed for contaminants contained

various pollutants, including heavy metals. At times of low water discharge, contaminant levels exceeded limits set by Mexican and international water quality standards (Cháidez, 2011). Mexico's current wastewater treatment system is ineffective at handling these high levels of contaminants, according to research for the peer reviewed journal *Water*, conducted by José de Anda and Harvey Shear. There were 2536 wastewater treatment facilities out of operation in 2021, and Mexico lacks regulations on industrial pollution, including organic micropollutants, industrial chemicals, and pharmaceuticals, all of which flow into surface water (de Anda, 2021). Even if Mexico were to begin passing necessary regulations, the traditional gray wastewater treatment systems in place would be unable to handle these advanced pollutants (de Anda, 2021).

Green wastewater treatment infrastructure can help solve these problems by easily and effectively treating polluted water. Reyes's review of stormwater treatment wetlands found that artificial wetlands placed to intercept stormwater runoff from upstream were able to reduce pollutant amounts by 76% (Reyes, 2023). Additionally, wetlands used to treat urban runoff from roads and parking lots reduced runoff volume by 37% and pollutant concentration by 81% (Reyes, 2023). Constructed wetlands have been tested to be one of the most effective ways to treat the difficult micropollutants that Mexican gray infrastructure is currently ineffective at treating, such as industrial and pharmaceutical waste (Stefanakis, 2019). After being treated, the water can be safely reused or discharged into bodies of water without harming the environment. For polluted agricultural runoff, Moeder and her colleagues suggest vegetated trenches as a solution. Vegetative trenches filled with waste-absorbent plants can be built to divert agricultural runoff, naturally treating waste and preventing runoff from flowing into surface water sources (Moeder). This use of green infrastructure is ideal for rural farming communities because of its cheap and simple design.

Implementation and Limitations

The various benefits of green water treatment infrastructure make it a key solution to be implemented in Mexico. The most feasible type of green infrastructure for combating water insecurity in urban areas is the vertical flow constructed wetland (VFCW) utilizing artificial aeration technology. VFCWs function by intermittently discharging wastewater into the wetland, letting the wetland reoxygenate between treatment cycles, then letting the water passively seep through layers of algae, plant roots, fine sand, and then gravel. Below the wetland is a non-permeable layer of material such as concrete, and outlet pipes to extract the newly treated water. In order to improve this design for urban use, Stefanakis's paper suggests using artificial aeration, a method for providing extra oxygen to the wetland by blowing small bubbles along the bottom layer (Stefanakis, 2019). This technology greatly reduces the area demand of these systems to just 0.5 m² per PE, meaning the area needed to treat the waste generated by 1 person (Stefanakis, 2019). Gray water treatment infrastructure generally falls between 0.2 to 0.5 m² per PE (Stephanakis, 2019). This makes aerated VFWCs ideal for urban areas where space may be limited, as they can fit within the same footprint as conventional technologies. Rural areas on the other hand can rely on more generic and less space efficient green infrastructure that doesn't require the same specialized equipment. In order to implement green infrastructure for wastewater treatment, multiple systems should be used in a sequence. For example, a vegetated trench or retention pond can manage runoff and remove sediment and debris, then an artificial wetland or a series of wetlands can remove organic and industrial waste, and finally the water can be used to recharge groundwater or irrigate crops. Additional sanitization methods such as UV light or chlorine must be utilized to make the treated water fully safe to drink. Green infrastructure systems like this offer many benefits over traditional water treatment infrastructure, such as requiring a low energy input, needing little maintenance, their tendency to self-improve over time, and their ability to provide green areas for recreational or educational purposes (Malaviya, 2012). Green infrastructure such as artificial wetlands and lagoons also require only 10-15% of the energy used by gray infrastructure methods, meaning the energy demand can be easily covered by renewable sources like wind or solar (Stefanakis, 2019). Rural communities see additional benefits from green infrastructure, as industrial treatment plants are often too expensive or technically challenging to be feasible and green

infrastructure is energy efficient enough to work off the grid. Implementation of green infrastructure in Mexico would be a long term solution to water scarcity, as it could take years to fully integrate green infrastructure into cities. In the short term, small green infrastructure systems can be built by small community initiatives to treat clusters of homes or individual large buildings, providing clean water, reducing pollution, and making more beautiful public spaces without needing extensive construction.

The costs of building extensive green infrastructure in Mexico can be estimated by comparing the costs of similar projects from Sandra Naumann's report on green infrastructure in Europe. Considering that the cost of European wetlands restoration projects have been about $2,930/acre, and extensive urban green space renewal can cost up to $472,000/acre (Naumann, 2011), urban aerated VFCWs might cost about $500,000/acre and rural artificial wetlands about $5,000/acre with lower space efficiency. Gray infrastructure systems could be slowly phased out and replaced by green infrastructure as they age, so funding could be slowly raised over time. Funding for these projects could come mainly through donations and volunteer work. Mayan Huerta's 2023 survey of Mexico City residents' found that 69% of people surveyed used urban green spaces frequently and 66% stated that green spaces were important to their wellbeing (Huerta, 2023). However, the majority of people stated that urban green spaces in their area were of poor quality, and only 12% rated them as excellent quality (Huerta, 2023). This indicates that a large number of Mexicans want more quality green spaces in their cities, so they may be willing to donate or volunteer to aid in the construction or maintenance of green infrastructure.Campaigns or petitions could be organized to secure public funding. In rural areas, workers could also be pulled from local communities and paid to work on these projects, putting more money into low income areas.

The usage of green infrastructure to treat wastewater does have limitations. Researchers have flagged concerns over whether the toxic pollution discharged into wetlands could degrade them over time (Malaviya, 2012). Even in a controlled environment, artificial wetlands could require extra maintenance and close monitoring to ensure that the level of pollutants doesn't cause negative effects on the infrastructure, which might increase costs. Additionally, the efficacy of wetlands for water treatment is highly variable depending on how they are designed and implemented (Malaviya, 2012). In order to mitigate this, gray infrastructure can be used in tandem with green infrastructure as a backup system for when conditions are poor for the use of things like wetlands and ponds. Also, local governments or organizations should optimize their green infrastructure systems to fit the environmental conditions in their location, such as by utilizing the readily available plants and natural water features that thrive in their region. Despite the drawbacks, green water treatment infrastructure remains one of the best solutions to combat water scarcity by mitigating the environmental impact of the overexploitation of water resources and environmental pollution in Mexico.

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