





Analysis of the technical and environmental feasibility of implementing microdams with recycled materials in rural areas

Análisis de la viabilidad técnica y ambiental de la implementación de micropresas con materiales reciclados en zonas rurales

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




Abstract



This project analyzes the technical and environmental feasibility of implementing micro-dams constructed with recycled materials and sustainable resources in rural areas. The research arises from the context of drought affecting more than 60% of Mexican territory, making the development of accessible alternatives for water harvesting and storage urgent. The proposal consists of the design and construction of a small-scale micro-dam, made with construction waste such as concrete, blocks, sand, and gravel, and waterproofed using nopal cactus mucilage as a natural and biodegradable alternative. The results obtained from monitoring the prototype during precipitation events allowed for the evaluation of its hydraulic and structural behavior, demonstrating adequate water retention capacity and favorable performance of the natural waterproofing agent. This approach contributes to the sustainable management of water resources, promotes the reuse of materials, and strengthens the resilience of rural communities to water scarcity and climate change.

Resumen

El presente proyecto analiza la viabilidad técnica y ambiental de la implementación de micropresas construidas con materiales reciclados y recursos sostenibles en zonas rurales. La investigación surge ante el contexto de sequía que afecta a más del 60% del territorio mexicano, lo que hace urgente el desarrollo de alternativas accesibles para la captación y almacenamiento de agua. La propuesta consiste en el diseño y construcción de una micropresa a escala, elaborada con residuos de la construcción como concreto, block, arena y grava e impermeabilizada mediante el uso de mucilago de nopal como alternativa natural y biodegradable. Los resultados obtenidos a partir del monitoreo del prototipo durante eventos de precipitación permitieron evaluar su comportamiento hidráulico y estructural, mostrando una adecuada capacidad de retención del agua y un desempeño favorable del impermeabilizante natural. Este enfoque contribuye a la gestión sostenible del recurso hídrico, promueve la reutilización de materiales y fortalece la resiliencia de comunidades rurales frente a la escasez de agua y al cambio climático.

Analysis of the technical and environmental feasibility of implementing micro-dams with recycled materials in rural areas.		
Goal	Methodology	Contribution
 To assess the technical and environmental feasibility of implementing micro-dams built with recycled materials in rural areas, which counteract water scarcity and contribute to the sustainable development of rural areas.	 Analysis of the implementation of recycled materials for construction.  Determining the causes of water scarcity in rural areas.  Prototype construction process.  Analysis of results obtained and discussion.	 The study demonstrates the technical feasibility of building micro-dams using recycled construction materials.  The project presents an economical, replicable and socially acceptable solution for rural communities affected by water scarcity.

Microdam, Water resource, Recycling.

Análisis de la viabilidad técnica y ambiental de la implementación de micropresas con materiales reciclados en zonas rurales.		
Objetivo	Metodología	Contribución
 Evaluar la viabilidad técnica y ambiental de la implementación de micropresas construidas con materiales reciclados en zonas rurales, que contrarresten los escases de agua y contribuya al desarrollo sostenible de las áreas rurales.	 Análisis de la implementación de materiales reciclados para la construcción.  Determinación de las causas de zonas rurales con escases de recurso hídrico.  Proceso de construcción del prototipo.  Análisis de resultados obtenidos y discusión.	 El estudio demuestra la viabilidad técnica de construir micropresas mediante el uso de materiales reciclados de la construcción.  El proyecto presenta una solución económica, replicable y socialmente aceptable para comunidades rurales afectadas por la escasez hídrica.

Micropresa, Recurso hídrico, Reciclaje.

Area: Promotion of frontier research and basic science in all fields of knowledge

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Introduction

Currently, the world is increasingly affected by climate change and water scarcity. We need to research sustainable solutions that benefit vulnerable regions. That is why, at the global level, the analysis of the SDGs represents one of the greatest global consensuses, which were agreed upon in 2015 by the 193 member countries of the United Nations [UN] General Assembly and are represented by 17 goals and 169 targets whose purposes are to end poverty, fight inequality and injustice, and address climate change without leaving anyone behind. For the present research, we consider the analysis of SDG No. 6 - Clean water and sanitation, which guarantees the availability and sustainable management of water and sanitation for all; No. 11 - Sustainable cities and communities, focused on making cities and human settlements inclusive, safe, resilient and sustainable; and No. 13 - Climate action, focused on taking urgent action to combat climate change and its impacts.

This leads us to analyse proposals that favour the development of rural areas. Climate action, focused on taking urgent action to combat climate change and its impacts. This leads us to analyse proposals that favour the development of rural areas by promoting the quality of clean water supply, livestock and agriculture focused on sustainability.

Climate variability and events 2025

The study of the technical and environmental feasibility of implementing micro-dams with recycled materials in rural areas is focused on meeting the SDGs and minimising the effects of drought.

Justification

Micro-dams are artificial water bodies that have multiple uses, as they are used for domestic consumption, irrigation for agricultural activities, including watering holes for livestock, fishing, aquaculture and recreation. According to Hernández-Avilés et al. [2007], nearly 20 million people in Mexico are connected to these small bodies of water, which are at the heart of a series of economic and social activities that contribute to the general well-being of the population. [Aldama-Rojas, June 2011]

That is why the analysis of the technical and environmental feasibility of micro-dams is proposed in rural areas that benefit the sustainable growth of the population by promoting food production, thus meeting basic needs in the face of water scarcity.

Theoretical framework.

Some research has found that in the community of San Jerónimo Silacayoapilla, in the district of Nochixtlán, Oaxaca, Mexico, the process of building micro-dams using ferrocement began, as it is innovative in the construction of small dams. It has advantages such as the slenderness of its screen, its speed of construction and its cost-effectiveness compared to other construction systems such as reinforced concrete or masonry, mainly due to the transport of industrialised materials to inaccessible places such as the geography of San Jerónimo Silacayoapilla.

The construction of the dam will provide significant benefits to the quality of life in these types of dispersed communities, with the conscious intention that any productive project they develop will require water. [Margarito Ortiz Guzmán, August 2012]

The micro-dam consists of curved shells, which are built vertically, with three types of mesh frameworks and a 5-7 cm thick cement-sand mortar layer.

Article cement-sand mortar, between 5 and 7 cm thick.

The shell has intermediate reinforcements of the same material in a horizontal and vertical position, called tympanums and gussets, respectively. [Margarito Ortiz Guzmán, August 2012]

How does the micro-dam work?

Its main functions include: Water storage: It is used to collect and store water during the rainy season for later use during the dry season or in times of scarcity. Flood control: It helps regulate the flow of water in rivers and streams, reducing the speed and volume of water during periods of heavy rainfall, which mitigates the risk of flooding downstream. Aquifer recharge:

They allow stored water to infiltrate the soil, contributing to the recharge of underground aquifers, which benefits the availability of water in wells and springs.

Irrigation: They supply water for agricultural irrigation, ensuring a constant source of water for crops. **Sanitation and water supply:** In some rural communities, micro-dams are used to provide drinking water or for wastewater treatment. **Power generation:** Although their capacity is limited, some micro-dams may include micro-hydro systems. [Trejo Torres, Rodríguez Uribe, & Velázquez Lucho, 2024] **Materials and Methods Construction process.** The construction of the micro-dam is carried out through a series of technical steps, which vary according to the size and function intended for the construction of the micro-dam, which depend on: **Stage 1.- Site selection.** This allows for the study of the terrain, identifying a location that allows for the capture of the greatest amount of runoff water, where the topography is the main natural element to consider, as well as ensuring that the terrain is stable and that there is no risk of landslides or erosion.

It is important to identify areas that are vulnerable to water scarcity due to droughts. **Stage 2.- Technical design.** At this stage, the dimensions of the micro-dam and the main function of the storage requirements are determined, the characteristics of the retaining wall are determined, and the recycled materials and key structural elements are selected. Since the publication of the General Law for the Prevention and Comprehensive Management of Waste, construction waste is considered special waste; its definition is: "Special Waste: This is waste generated in production processes that does not meet the characteristics to be considered hazardous or urban solid waste, or that is produced by large generators of urban solid waste." [Mena, 2016]

The recycling of construction materials is a key practice in the field of sustainable construction. Its main objective is to minimise the amount of waste generated during demolition, renovation and new construction, while reducing the need to extract and process new resources. This strategy not only helps to reduce the sector's environmental impact, but also promotes a circular economy that benefits both the environment and society. [ShiningMéxico, 2025]

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Currently, one of the biggest environmental problems facing Mexico City is the amount of solid waste generated by its population. Of particular note is construction and demolition waste [CDW], which currently lacks adequate management to promote its reuse or recycling and amounts to 3,000 tonnes per day. [Rivera Mera, 2009] **Block.**

Blocks are defined as a basic element for the construction of walls. The types of blocks differ in their geometry and manufacturing processes. The raw materials for the production of concrete blocks are cement, sand, gravel or other stone aggregates, and water. Natural aggregates can be replaced by Article aggregates made from recycled concrete. [Castro, 2017] **Brick.** The era of fired brick began around 3,500 BC, with firing giving it a solidity similar to stone, but with the versatility of being able to be moulded before the firing process. Brick manufacturing was faster and cheaper than carving stones, which made fired bricks a highly valued commodity. Industrialisation allowed for greater diversity in brick designs and sizes. The standardisation of industrial processes enabled the creation of more uniform and higher quality bricks. [Luna A, 2023] **Cement.** Today, cement is one of the main materials used in construction, for houses, buildings and bridges. According to studies carried out by the Spanish Institute of Cement and its Applications [IECA], cement originated around 1600BC, as a result of a mixture of limestone, water, sand and aggregates.

This new material could be moulded while wet, as it hardened when dry, with remarkable strength and resistance. [Rocha D, 2020] **Sand.** Sand is known as a material whose particles vary in size between 0.063 and 2 millimetres. It is used in concrete mixtures according to the requirements of use: for example, S1, S2, S3, P1 and C2, where S is sulphate resistance, P is permeability and C is corrosion resistance. It is also one of the most abundant materials on the planet and, due to its characteristics, can be easily compressed and used to reinforce structures. According to ARQHYS magazine. Architecture, the granulometry of sand is classified into coarse, medium and fine sand.

Coarse sand is sand that passes through a 5 mm mesh but is retained by a 2 mm mesh; medium sand passes through a 2 mm mesh and is retained by a 0.5 mm mesh; fine sand passes through a 0.5 mm mesh but is retained by a 0.2 mm mesh. [Rocha D, 2020] Gravel. Gravel is an aggregate with a smaller grain size than crushed stone. It is classified according to size: Coarse: diameter of 1.0 to 2.5 cm. Used for base formation and asphalt mixes, in roads and concrete. Medium: diameter from 0.7 to 1.0 cm.

Used for base formation and asphalt mix, in roads and concrete. Fine: diameter from 0.25 to 0.5 cm. It is mainly used in the composition of concrete and asphalt, and also in floors and facades. [Becerra Becerra, J. E. [2019].] Lime. Slaked lime is hydrated calcium oxide. It is a powerful base and has the appearance of white earth, hence its name “alkaline earth base”. Slaked lime does not lose its water until it reaches over three hundred degrees, at which point it becomes quicklime. [E, 1926] Nopal mucilage.

Nopal mucilage in general [Opuntia spp.], obtained from cladodes, is a hydrocolloidal, heteropolysaccharide substance [with residues of arabinose, galactose, rhamnose and xylose as neutral sugars]; its molecular structures are polyelectrolytes, highly branched and with a molecular weight [MW] in the order of millions of Da. [Vargas-Rodríguez, 2016]

Methodology

For this analysis, a micro-press prototype was constructed, which will allow for its evaluation and operation in rural areas or areas affected by drought, with the aim of being constructed from recycled materials.

The first step in implementing the prototype was to collect surplus materials from various construction sites to which we had access, as can be seen in Figure 1. These materials were selected based on their availability, physical condition and potential for reuse, as can be seen in Figures 2 and 3. Subsequently, a conditioning and preparation process was carried out, with the aim of facilitating their handling and ensuring proper behaviour when in direct contact with water, thus ensuring their functionality within the micro-dam construction system.

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Box 1



Figure 1

Collection of excess sand and gravel

Source: [Own work 2025]

Box 2



Figure 2

Concrete waste, with sand and gravel.

Source: [Own work 2025]

The next step consisted of conditioning the collected materials, which involved selecting, sifting, and crushing the larger pieces, as can be seen in Figure 4.

This process resulted in a more homogeneous grain size, facilitating its handling and subsequent integration into the construction system. Likewise, the treatment of the material ensured better workability during its application and adequate performance within the micro-dam structure.

Box 3**Figure 3**

Concrete waste, with sand and gravel.

Source: [Own work 2025]

Box 4**Figure 4**

Selection, crushing and screening of materials

Source: [Own work 2025]

Once the leftover materials had been collected and conditioned, the nopal mucilage was prepared, which is used as a natural waterproofing agent in the construction of the micro-dam, as can be seen in Figures 5 and 6. This process requires a prior period of rest and fermentation lasting several days, which is necessary for the mucilage to achieve the optimal physicochemical properties that guarantee its correct functionality and greater effectiveness as a waterproofing agent. Proper preparation of the mucilage is essential to improve the cohesion of the material, reduce permeability, and ensure better performance of the construction system in contact with water. reduce water infiltration and analyse its performance under controlled conditions.

Box 5**Figure 5**

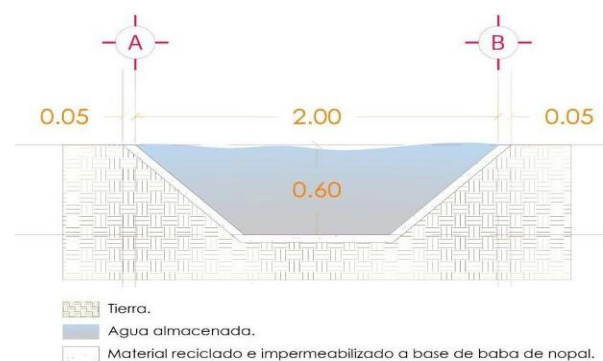
Selección de nopal, limpieza, pelado y triturado de la planta. Fuente: [Autoria propia 2025]

Box 6**Figure 6**

Soaking the nopal cactus in water, lime and granulated salt.

Source: [Own work 2025]

This prototype is a fundamental step in assessing the technical and environmental viability of the proposed micro-dam, as shown in Figure 9.

Box 7**Figure 7**

Scale model prototyping of the micro-enterprise design.

Source: [Own work 2025]

In order to validate the construction proposal, a scale model prototype was developed [see Figure 7], which allowed for the evaluation of the technical performance of the system and the generation of preliminary results, both favourable and unfavourable, for subsequent analysis. The prototype is 2.00 m wide and 0.60 m deep, and incorporates a 5 cm thick base made from recycled construction waste materials, as can be seen in Figure 8.

Box 8



Figure 8

Construction of the excavation for the prototype

Source: [Own work 2025]

Likewise, the structure was waterproofed by applying nopal mucilage, used as a natural waterproofing agent, with the aim of

Box 9



Figure 9

Final prototype, with a layer of recycled materials and application of a layer of natural waterproofing

Source: [Own work 2025]

Box 10



Figure 10

Filling in the micro-company

Source: [Own work 2025]

Its operation was monitored during the first five days after filling the prototype, at two times of day, 8:00 a.m. and 6:00 p.m., to determine whether water loss was due to evaporation or filtration. The data are recorded in Table 1.

Box 11

Table 1

Recording of results and measurements

hour	Día 1	Día 2	Día 3	Día 4	Día 5
8:00	60cm	56 cm	53 cm	51 cm	47 cm
18:00	58 cm	55cm	51cm	48 cm	45 cm

Results

Once construction of the scale model prototype was complete, the observation and evaluation of its hydraulic and structural behaviour began during the first rainfall in May 2025, which allowed for the collection of surface runoff water, enabling analysis of the system's performance under real operating conditions.

The structure performed well mechanically, with no cracks, detachments or significant deformations observed, confirming the correct integration of the recycled materials, as can be seen in Figure 10.

Conclusions

The results obtained during the monitoring period of the micro-dam prototype are presented in Table 1, which records the water levels measured at 8:00 a.m. and 6:00 p.m. for five consecutive days. On the first day, the micro-dam reached a maximum height of 60 cm in the morning, decreasing to 58 cm in the afternoon, which shows a minimal loss mainly attributable to natural processes such as evaporation.

Over the following days, a gradual decrease in the stored water level was observed. By day five, the level had dropped to 47 cm in the morning and 45 cm in the afternoon, representing a moderate cumulative reduction in relation to the initial volume. This behaviour indicates that the structure achieved adequate water retention, without presenting abrupt losses that could be associated with significant leaks in the base or walls.

Analysis of these results suggests that the recycled materials used in construction, in combination with nopal mucilage as a natural waterproofing agent, performed favourably in terms of water retention. Although 100% efficiency was not achieved due to the heterogeneous nature of the construction waste used, the behaviour observed was stable and functional for temporary water storage purposes.

Likewise, the data reflect the influence of environmental conditions on the system's retention capacity. During the evaluation period, corresponding to the month of May 2025, high temperatures were recorded, which increased the evaporation rate and contributed to the progressive decrease in the water level. This factor confirms that environmental and climatic impact is a determining factor in the performance of this type of infrastructure, particularly in regions with high temperatures and prolonged periods of low water flow.

Overall, the results obtained allow us to conclude that the micro-dam prototype presents a favourable and viable technical response for its application in rural communities, offering a sustainable alternative for the storage of runoff water. However, it is recommended that complementary strategies be considered to reduce evaporation, as well as conducting tests on a larger scale and in different climatic periods, in order to strengthen the efficiency and durability of the system.

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It is also considered that an analysis should be carried out to cover the water storage to prevent the accumulation of bacteria.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Contribution of the authors

Trejo-Torres, Zaira Betzabeth: Contributed to the research idea and the integration of the research.

Rodríguez-Uribe, Juan Carlos: I contributed to the research and methodology advice.

Benitez-Alonso, Margarita: I contributed to the advice for the construction of the prototype.

Availability of data and materials

The data obtained in this research are available upon request to the corresponding author. This includes the experimental results and the methodological process for the development of the prototype.

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Abbreviations

ODS	Sustainable Development Goals.
RC&D	Construction and Demolition Waste.

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