

SYSTEMIC FEASIBILITY STUDY FOR POTABILIZATION OF WATER FROM THE SAN JORGE RIVER, POWERED BY PHOTOVOLTAIC SOLAR ENERGY



ABSTRACT

This preliminary study aimed to diagnose the conditions of access to, quality of, and use of drinking water in Indigenous communities located along the banks of the San Jorge River, as well as to evaluate the technical, environmental, and climatic feasibility of implementing a water purification system powered by photovoltaic solar energy. The research was conducted by an interdisciplinary team from the ECOCEANOS Corporation, in collaboration with experts from the University of the Caribbean and the University of Córdoba, through fieldwork, direct observation, and technical analysis of the territory. The study identified a recurring public health problem associated with the consumption of untreated water, resulting from direct river intake and the absence of water purification systems in the communities evaluated. This situation particularly affects pregnant women, who are at greater risk of contracting waterborne diseases such as toxoplasmosis, as well as children and the elderly.

Additionally, climatic conditions, solar radiation levels, and average temperatures in the area were analyzed to determine the feasibility of operating a photovoltaic system as the primary energy source. The results confirmed that the territory has favorable conditions for solar power generation, thus providing technical support for the implementation of an autonomous water extraction and purification system. This preliminary study served as the basis for the project design, ensuring its social, health, and technical relevance.

Keywords: water treatment, solar energy, renewable energy source

INTRODUCTION

Access to safe drinking water remains one of the main structural problems in rural and indigenous communities in Colombia, especially in the Caribbean region. In the riverine territories of the San Jorge River, where Zenú indigenous communities reside, water is a central element for life, culture, and productive activities; however, its use for human consumption is carried out under precarious conditions, without adequate treatment or purification processes. This situation has generated direct impacts on community health, associated with the consumption of contaminated water and constant exposure to biological and chemical agents present in the river.

The Zenú indigenous communities of the Upper San Jorge, located in the rural area of the municipality of Puerto Libertador, department of Córdoba, face a combination of social, environmental, and health vulnerabilities. Their direct dependence on the river for activities such as artisanal fishing, subsistence farming, and domestic water supply, coupled with the lack of basic infrastructure, increases the risks for the population. In particular, pregnant women, children, and the elderly are more susceptible to waterborne diseases, including gastrointestinal infections and conditions such as toxoplasmosis, associated with the ingestion of water under unsafe conditions.



Added to this context are the effects of climate change, manifested in high temperatures, variability in river flows, and environmental degradation of the territory, which exacerbate the difficulties in accessing quality water. Faced with this scenario, it is a priority to identify sustainable technical solutions, adapted to rural conditions and culturally relevant, that guarantee access to drinking water without increasing dependence on conventional or high-cost energy systems.

Photovoltaic solar energy emerges as a viable and strategic alternative for these types of territories, given the high levels of available solar radiation and the lack of reliable electrical grids. The combination of small-scale water purification systems with renewable energy sources has proven to be an effective solution for isolated communities, enabling the production of drinking water with lower operating costs and a reduced environmental impact.

Within this framework, this preliminary study is presented as a fundamental technical and social input to support the formulation of a solar-powered reverse osmosis water extraction and purification project aimed at improving the health and well-being of the Zenú indigenous community of Alto San Jorge. The study seeks to provide evidence supporting the relevance of a comprehensive, sustainable intervention managed in collaboration with the community.



METHODOLOGY

The project methodology is structured in five complementary phases, designed to ensure technical rigor, community participation, and long-term sustainability of the solar photovoltaic-powered water purification system.

1. Territorial and Social Diagnosis

A preliminary diagnosis was conducted in the Zenú indigenous communities of Alto San Jorge through field visits, direct observation, and dialogue with traditional authorities and families. This phase allowed for the identification of water sources used, consumption practices, the main health impacts, as well as the social and organizational conditions of the community. Simultaneously, climatic and environmental data for the territory were collected to assess the feasibility of the photovoltaic system.

2. Technical Analysis and Technology Selection

Based on the information gathered, different technological alternatives for water treatment and energy generation were evaluated. A small-scale reverse osmosis water purification system, powered by a solar-direct photovoltaic system, was selected, considering criteria of energy efficiency, ease of operation and maintenance, and adaptation to a rural context. This phase benefited from the technical support of university experts.

3. System Design and Operational Planning

The solar system was sized (number of panels, installed power, and frequency inverter with MPPT), as well as the hydraulic and potable water storage systems. Simultaneously, a community management model was defined, establishing roles, responsibilities, and operating protocols, aligned with the ECOCEANOS Corporation's work methodology.

4. Implementation and Community Training

During the implementation phase, the community actively participated in the system's installation. Theoretical and practical training processes were developed for selected community members, especially women and youth, on the operation, maintenance, and monitoring of the system. These activities were complemented by fieldwork and ongoing technical support.

5. Monitoring, Evaluation, and Sustainability

Once operational, the system incorporates technical monitoring tools, supported by intelligent analytics, to record water production, system performance, and water quality conditions. The management will be in charge of an Indigenous Secretariat, made up of trained members of the community, which guarantees local ownership, capacity building and the technical and organizational sustainability of the project over time.



RESULTS AND DISCUSSION

The results of the previous study demonstrate that the problem of access to safe drinking water in the Zenú indigenous community of Alto San Jorge is a critical factor that directly impacts the population's health. Field visits and community work confirmed that a significant number of families consume water drawn directly from the San Jorge River, without any treatment, due to the lack of water purification infrastructure and the limited alternatives available in the area.



This situation has a disproportionate impact on the most vulnerable groups in the community, particularly pregnant women and children. For pregnant women, consuming unsafe water increases the risk of waterborne diseases, including toxoplasmosis, which poses a significant threat to maternal and fetal health. Constant exposure to contaminated water, coupled with limited access to healthcare, increases the likelihood of pregnancy complications and affects the overall well-being of families.

In children, the study identified a high incidence of gastrointestinal, parasitic, and dermatological diseases associated with the consumption of untreated water. These illnesses not only affect their immediate health but also impact their physical, nutritional, and educational development, leading to recurrent school absenteeism and general weakness. The dependence on the river as the primary

water source, in a context of pollution and variable flow, exacerbates these conditions and perpetuates cycles of health vulnerability.

From an environmental perspective, the pollution of the San Jorge River is linked to factors such as waste discharge, upstream production activities, and the lack of adequate sanitation systems. These elements increase the load of microorganisms and sediments in the water, making it unsuitable for direct consumption without treatment. The community is aware of this problem but lacks the technical and energy resources to address it independently.



(Lee, 2004) argues that:

Water and sanitation are one of the main drivers of public health. I often refer to them as "Health 101," meaning that as soon as access to safe water and adequate sanitation facilities can be guaranteed for everyone, regardless of their living conditions, a major battle will have been won against all kinds of diseases.

An article published by Scielo (2013) states that:

- Contamination by metals, chemical residues, and antibiotics remains the main factor in water pollution, which seriously impacts human health. According to the World Health Organization (WHO), the consumption of contaminated water and the lack of access to improved sanitation services are associated with more than 4,000 premature deaths per year in Latin America.

It also points out:

...But that's not all. Prolonged exposure to water contaminated with pesticides, metals, antibiotics, and radioactive waste is associated with toxoplasmosis in pregnant women, cancers, kidney failure, cognitive problems, and other non-communicable diseases. The presence of these contaminants is attributed to poor agricultural practices, mining, inadequate sanitation systems, and other industrial practices.

In addition to these problems, there are those associated with gallstones and kidney stones, as well as other diseases such as liver and blood disorders, associated with nitrites, which, although not frequent, also occur.

In the case of water contamination in some isolated communities, the fundamental cause is that the main sources are rivers or wells containing organic matter. In these sources, the low chlorine levels at which the water reaches consumers are significant, due to transport in tanker trucks or tractors with tanks during long journeys.

Pestana (2025) states that:

- In 2024, to determine bacterial contamination of the water, 245 samples were scheduled to be taken at 20 key points established along the river under study. The stratification of the risk posed by each city's exposure to the water allowed for the following classification: villages with low risk: 0; villages with moderate risk: 8; villages with high risk: 23.



Thus, cities with moderate risk represent 26% and cities with high risk represent 74%.

It can be concluded from the above that where water is not properly treated, there is a high risk of contracting related diseases, primarily diarrheal diseases and parasitic infections.

However, there are programs that counteract the effects of water pollution with very good results. One example is the Maternal and Child Health Program, which has achieved some of the lowest infant and maternal mortality rates in the world.

The energy consumption of a water treatment plant depends directly on the volume of water to be processed. This is why this work proposes small water treatment plants capable of operating with low energy consumption, which allows them to be powered primarily by photovoltaic solar panels (Moraguez and Carballo, 2020).

Other types of plants exist worldwide for treating water on a small scale, but they are adapted to conditions that do not meet the expectations of small, isolated communities.

Solar panels can be of three types:

- Photovoltaic solar panels
- Thermal solar panels
- Hybrid solar panels (photovoltaic + thermal)

The photovoltaic solar panel, responsible for transforming energy from the sun into electricity, has been selected for this type of water treatment technology. With increasingly lower prices, photovoltaic modules are emerging as a great clean alternative for generating electricity (or part of it) in the residential sector, hospitals, businesses, schools, etc. (ENDEF. Solar Solution, 2017).

According to Moreno (2011), the most common photovoltaic solar panels are:

- Monocrystalline (silicon)
- Polycrystalline (silicon)
- Amorphous.

The most widely used are polycrystalline panels. There are many ways to use photovoltaic panels, depending on the intended purpose: from off-grid panels connected to the national electricity grid, to hybrid off-grid systems, among others.



Aguilar and Gómez (2020) propose that a Grid-Connected Photovoltaic System (GCPS) basically consists of a photovoltaic generator coupled to an inverter that operates in parallel with the conventional electrical grid.

The GCPS concept is compatible with a wide range of applications, from multi-megawatt power plants to small systems of a few kilowatts. In this case, the work focuses on small and medium-sized systems, such as those that can be installed in a building.

Based on the results of this research, a photovoltaic system connected to the National Interconnected System (SEN) is proposed. This ensures the water purification service even on cloudy days.

Small water treatment plants for drinking water supply are facilities intended for small, isolated communities and emergency situations, designed for minimal energy consumption, which allows them to operate using renewable energy sources (NOVAGRIC, 2016).



Many companies worldwide are dedicated to the design, construction, and large-scale production of small-scale water purification plants. This project proposes a plant with special characteristics: low production capacity, as it is intended for low-density population settlements. This ensures low energy consumption, allowing it to operate using photovoltaic panels, given that the average solar incidence in the area is between 5.0 and 6.0 kWh/m². Another distinguishing feature is the use of ozone as a purification agent, which has the advantages of being environmentally friendly and reducing operating costs by eliminating the need to purchase chlorine or hypochlorinators.

This proposal is directly related to calls to promote production chains as part of the planning process. Through collaboration between the university and other companies allied with territorial and business projects, small-scale plants of this type can be designed and mass-produced, guaranteeing acceptable drinking water quality using national resources and energy produced by domestically manufactured photovoltaic panels.

(Doménech, 2004) states that:

The disinfection of drinking water is one of the water treatment processes that has generated the most controversy in recent times, due to the potential undesirable effects produced by different additives and treatments, both on organoleptic qualities and other possible health

effects. Thus, chlorine and ozone have become the two main disinfectants for drinking water, each with its advantages and disadvantages.

Chlorine is currently the most widely used chemical element for disinfecting water, but at the same time, it is considered one of the most reactive substances in the universe, capable of reacting with a vast number of chemical substances. This makes it an excellent water treatment agent, as it is capable of eliminating most human pathogens. However, recent studies have identified it as an ozone-depleting substance; they also maintain that, in incorrectly calculated proportions in drinking water, it can harm human health. This is why ozone is used, as it can be produced in the quantities necessary to achieve optimal levels of elimination of bacteria, mold, fungi, and viruses in drinking water. According to Doménech (2004), ozone can be generated within the treatment plant itself using well-established methods such as high-voltage electrolysis.



CLIMATIC CONDITIONS ANALYSIS

The analysis of climatic and environmental conditions conducted during the preliminary study confirmed the technical feasibility of using photovoltaic solar energy in the territory of the Zenú indigenous community of Alto San Jorge, in the rural area of the municipality of Puerto Libertador, Córdoba. Based on available climate records, field observations, and expert opinion, favorable conditions were identified for the continuous operation of a solar system for water purification.



In terms of temperature, the area experiences high average values for most of the year, ranging between 32°C and 40°C, especially during the dry season. While these temperatures pose a challenge to health and community activities, they indicate high solar incidence, a key condition for photovoltaic generation. Although high temperatures can lead to slight efficiency losses in the modules, these are considered manageable through proper system design, natural ventilation, and the selection of monocrystalline solar panels, which perform well in warm climates.

Regarding relative humidity, high levels were recorded, typical of a riparian ecosystem, with average values between 70% and 85%. While humidity can influence the corrosion of some electrical components, this factor was considered in the technical design, prioritizing resistant materials and adequate electrical protection. Humidity does not represent a significant limitation for solar generation, provided that basic protection and maintenance measures are adopted.

One of the most relevant findings of the study concerns the available hours of sunlight. The Alto San Jorge region experiences an estimated average of 4.5 to 5.5 peak sun hours per day, relatively constant throughout the year. This availability of solar radiation is sufficient to guarantee the daily operation of the proposed photovoltaic system, allowing the pumping and water treatment system to operate during peak radiation hours and producing the required daily volume of potable water.

Overall, the climatic data confirm that the region has optimal conditions for implementing an autonomous photovoltaic system capable of operating efficiently without relying on the conventional electrical grid. The stability of the sun hours, combined with predictable temperatures and environmental conditions, supports the selection of solar energy as the primary source for the water treatment system, ensuring its technical and operational sustainability within the Alto San Jorge context.



CONCLUSIONS

1. The previous study confirmed that the consumption of untreated water in the Zenú indigenous community of Alto San Jorge is a critical factor that directly affects community health, especially among pregnant women and children, who are more vulnerable to waterborne diseases.
2. It was evident that the lack of water treatment systems exposes the population to preventable diseases, including gastrointestinal infections and pathologies associated with water contamination, such as toxoplasmosis, reinforcing the need to guarantee a safe source of drinking water for human consumption.
3. The analysis of the region's climatic conditions led to the conclusion that Alto San Jorge has adequate levels of solar radiation, high temperatures, and climatic stability, making the implementation of a photovoltaic solar energy system to power a water treatment plant technically feasible.
4. It was determined that the combination of photovoltaic solar energy and reverse osmosis technology is an appropriate technical solution for rural and indigenous contexts, offering low energy consumption, reduced operating costs, and a lower environmental impact.
5. The study concluded that a solution based on stand-alone solar systems reduces dependence on conventional electrical grids, facilitating the continuous operation of the water treatment system in a territory with limited infrastructure.
6. Finally, it was confirmed that the collaboration between the ECOCEANOS Corporation, partner universities, and the indigenous community, along with the active participation of local leaders, is a key element for the effective implementation, community ownership, and long-term sustainability of the project.

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