Concept of a Water Treatment System for Water tanks in Single-Family Homes

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Abstract: Water is a vital resource for human health, but the lack of basic sanitation and potable water exposes the population to serious risks, such as taeniasis and cysticercosis. In Brazil, in particular, the common practice of storing water in residential tanks can, paradoxically, become a source of contamination. Given this problem, the present study proposes a water treatment system focused on reducing health risks for families who rely on this type of storage. The study began with a survey using questionnaires to identify the main issues related to the quality of water for human consumption. Subsequently, the QFD (Quality Function Deployment) methodology was applied to translate user needs into detailed and prioritized technical requirements. In the next phase, using the TRIZ methodology, it was possible to analyze inventive principles and, in conjunction with a morphological matrix developed through brainstorming, generate four initial concepts for the treatment system. Finally, a competitive analysis was conducted, resulting in the selection of the final concept. The system is designed to be installed after the water tank and operates in a sequence: first, a polypropylene filter removes suspended solids; next, an activated carbon filter eliminates chemical agents. The final disinfection stage is performed by ultraviolet (UV) radiation. For power, the system combines solar and electrical energy. Additionally, it incorporates a small pressurized pumping system to maintain ideal pressure in the residential plumbing and a multiparameter monitor to track water quality. The adopted methodologies proved effective in creating a functional concept. However, the system is still in a conceptual phase, requiring efficiency studies and sizing calculations to validate its performance and feasibility for residential use.
Keywords: Basic sanitation; water quality; water treatment

1. Introduction

Water is one of the most important resources for human health. When individuals live in conditions lacking basic sanitation, access to clean drinking water, sanitary education, and with poor water quality, they become more susceptible to diseases such as taeniasis and cysticercosis [1]. Unfortunately, data from 2020 reveal that 15.8% of the Brazilian population is not connected to the public water distribution network and depends on alternative sources such as wells and rainwater, which require prior treatment before human consumption [2].

This situation is reflected in the occurrence of deaths caused by the consumption of water contaminated with pathogens. In 2020, the mortality rate associated with poor water quality in Brazil was 4.14 per 100,000 inhabitants, totaling more than 8,500 deaths that year [3].

Recognizing the importance of ensuring that water intended for human consumption meets quality standards that protect health, Annex 1 of Annex XX of Consolidation Ordinance No. 5, dated September 28, 2017, from the Ministry of Health, establishes microbiological, physical, and chemical parameters that water must meet to be considered potable [4]. However, although Brazil has regulations regarding water quality, not all the population has access to this standard. Studies such as those by [5] and [6] indicate that many families are exposed to health risks due to the low quality of stored water. Among the problems identified by [6] are: improper storage, lack of water tank maintenance, and consumption of well water without proper disinfection. Additionally, [6] conducted bacteriological analyses in residential water tank and found bacteria in all evaluated containers. Furthermore, a study conducted by [5] revealed that 28.99% of respondents reported feeling ill or getting sick after consuming water from their water tank.

The need to ensure access to quality water as a preventive measure against disease must be treated as a priority. This issue aligns with Sustainable Development Goal (SDG) No. 6 – Clean Water and Sanitation, which reflects the global concern to guarantee access to potable water for all. However, a portion of the Brazilian population still faces barriers in accessing this essential resource.

In response to this problem, the present study applied methods such as Quality Function Deployment (QFD), Teoriya Resheniya Izobretatelskikh Zadach (TRIZ), and the morphological matrix to identify and propose a water treatment system solution capable of reducing health risks for families who use water stored in residential tanks.

2. Methodology

The Figure 1 presents the flowchart used in this study, providing a clearer illustration of the development process.

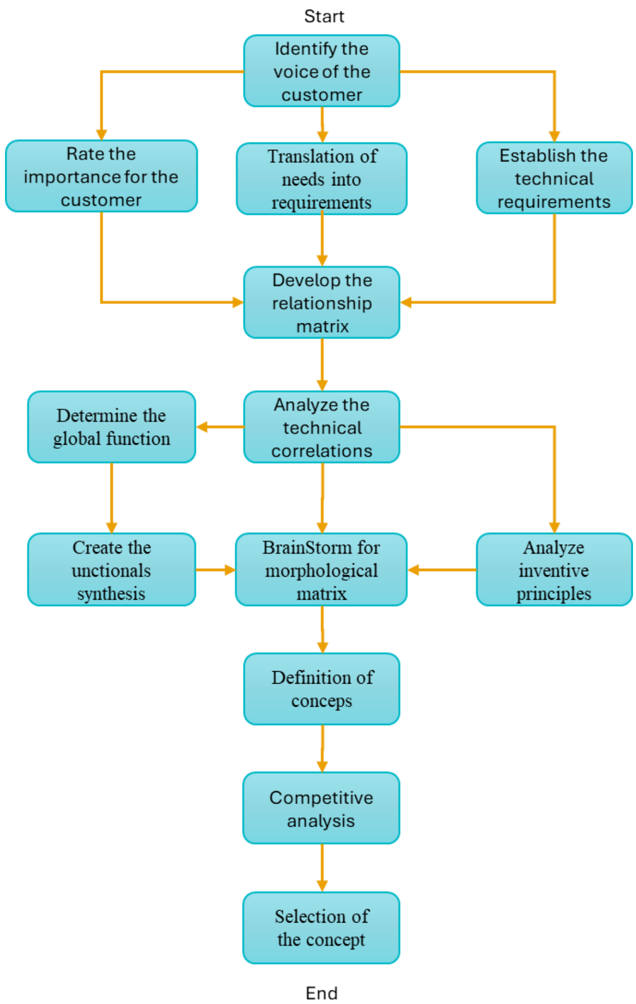
Initially, data were collected through questionnaires aimed at identifying the main issues related to the quality of water intended for human consumption. The survey sought to understand how the supply system operates, access to water, its storage conditions, water tank maintenance, and whether respondents had experienced any negative outcomes such as unpleasant taste or odor—or even episodes of illness caused by drinking the water.

The second phase involved applying the QFD methodology, which included translating the identified needs into requirements, establishing the technical requirements, rating their importance to the customer, developing the relationship matrix, and analyzing technical correlations. According to [7], Quality Function Deployment (QFD) is a customer-oriented product development approach that helps design teams structure new projects based on an evaluation of user needs. This method was developed in Japan by Yoji Akao and Shigeru Mizuno in the late 1960s and early 1970s.

The third phase encompassed constructing the Global Function, performing the Functional Synthesis, and developing the Morphological Matrix through brainstorming. Subsequently, by applying the TRIZ method, an analysis of the inventive principles was conducted. These processes led to the definition of four concepts. To arrive at the final concept, a competitive analysis was performed based on customer requirements and their importance of each requirement and customer, resulting in the selection of the winning concept.

TRIZ, developed by G. S. Altshuller in the 1940s, consists of systematizing inventive solutions through abstraction, compilation, and organization of effective heuristics. Although initially applied in traditional engineering fields, the method has since expanded to other areas such as information technology, politics, the arts, and management [8].

Figure 1 – Flowcart of the development process



3. Results and Discussions

The research revealed that several individuals have already experienced issues with the water in their homes. Out of the 73 participants who responded to the questionnaire, 40 reported encountering some type of problem. The most frequent difficulties reported by users when utilizing water from their water tanks, in descending order of occurrence, were: presence of dirt or particles, unpleasant taste, cloudy water, foul odor, water-related illnesses, chlorine taste, and surface foam.

Through the application of QFD, it was possible to identify user needs and translate them into requirements, organizing them in order of priority, as shown in Table 1.

Table 1. Requirement ranking

Requirements	Ranking
% of internal contamination	1º
Filter media lifespan	2º
Solution cost	3º
Maintenance cost	4º
Interval time between maintence	5º
Maintenance duration	6º
System lefespan	7º
Installation time	8º

Subsequently, the system's global function was developed, along with three functional syntheses. Based on these syntheses, a morphological matrix was constructed, as shown in Table 2. Together, these elements supported the formation of the concepts that were later evaluated.

To build the morphological matrix, the following key functions were considered: water collection, solid particle filtration, chemical contaminant removal, pathogenic agent neutralization, water quality monitoring, water storage, water distribution methods, and energy source.

With the objective of minimizing the impact of conflicts between requirements, the TRIZ methodology was applied to analyze these contradictions—except for the solution cost, which was excluded due to being inherently in conflict with all other requirements and solely related to lowering the overall price of the solution.

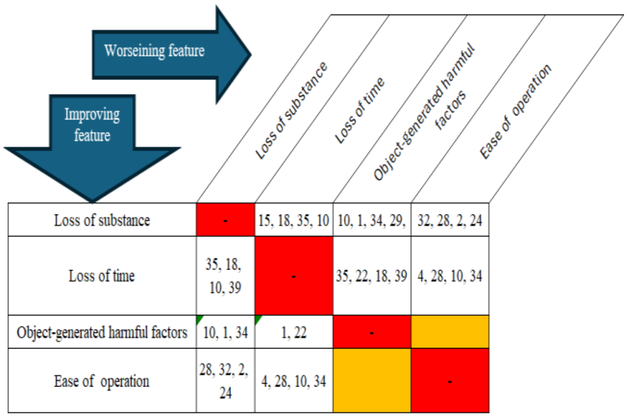
Table 2. Morphological Matrix

Function	Systems			
Water collection	Direct connection to the network	Submersible pump	Gravity	Centrifugal pump
Solid particle filtration	Polymeric filters	Sand filters	Activated carbon filters	Membrane filtration
Chemical contaminant removal	Activated carbon	Ion exchange	Reverse osmosis	Chemical adsorption
Pathogen neutralization	Controlled chlorination	Ozone	Ultraviolet light	Ultrafine membrane filtration
Water quality monitoring	pH sensors	Multi-parameter meter	Electrical conductivity sensors	Turbidity sensors
Treated water storage	Life fiber water tanks	Water tanks	Underground tanks	Sealed cistern
Water distribution	Pressurized network	By gravity	Automatic valves	Pumping
Energy supply	Utility companies	Solar	Wind	Battery

Through this conflict analysis, engineering parameters influencing both the requirements and their contradictions were identified. These parameters included: substance loss, time loss, ease of use, and side effects resulting from the object’s action. Based on this data, we applied the TRIZ method using the inventive principles illustrated in Figure 2 below, which guided the selection of the most appropriate conceptual solutions.

We applied 14 inventive principles from TRIZ to be analyzed and implemented in the concept generation process. Among these, the following principles were used:

Figure 2. Requirement Conflict



- Segmentation: Considered in the division of filtration processes
- Prior Action: The system was designed so the process is carried out in series rather than in parallel
- Mediator: Applied in filters for suspended solids, chemicals, and pathogens by placing the filtering media in quick-release vessels to facilitate maintenance
- Pneumatic or Hydraulic Construction: Incorporated in some concepts to achieve more energy-efficient water distribution
- Color Change: Transparency was considered to visually indicate when maintenance is needed
- Discarding and Regenerating Parts: Systems were designed for easy and low-cost maintenance through replacement of specific components

- Inert Environment: Some concepts adopted this approach to preserve water quality for longer periods

With the support of the tools used in this study such as QFD, TRIZ, and the morphological matrix four concepts were developed that meet the defined requirements, aiming to improve the quality of stored water in households.

3.1. Concept 1

This concept improves the water quality of properties connected to the public network.

It uses sand filtration to remove solid particles and eliminate chemical contaminants, followed by UV disinfection. Turbidity sensors monitor water quality in real time.

The treated water is stored in fiberglass water tanks and distributed through a pressurized network. The system operates with hybrid energy (solar + utility power), ensuring both efficiency and sustainability.

3.2. Concept 2

This concept is designed for properties without continuous water supply, collecting water from natural sources using a solar-powered pump.

Initial filtration is performed with activated carbon, alongside chemical adsorption that removes contaminants.

Controlled chlorination is used for disinfection.

Multi-parameter sensors ensure real-time monitoring before storage in a sealed cistern. Water is distributed by gravity, reducing pumping costs, while solar energy ensures complete autonomy.

3.3. Concept 3

Water is pumped from the water tank into a filtration system with polypropylene to remove suspended solids, followed by an activated carbon filter to remove chemical impurities.

Disinfection is handled via UV light placed in a chamber. After treatment, water is pumped to the home's water tank. The system is powered by solar energy.

3.4. Concept 4

Developed to meet high demands for treated water, this concept uses a centrifugal pump for water collection. A sand filter handles initial purification, while ozone disinfection ensures microbiological safety.

Sensors detect heavy metals, providing enhanced protection. The water is stored in underground tanks and distributed via pumping systems. The system runs on utility power, ensuring continuous operation.

3.5. Concept Selection

For concept selection, all gathered data were analyzed — including TRIZ, morphological matrix, and functional synthesis.

With the support of QFD, the concepts were treated as competing alternatives and evaluated based on their performance, as shown in Table 3.

Concept 3 stood out as the highest-rated, although some modifications were considered using TRIZ to develop a more robust final concept

Table 3. Analysis of the Concepts

Need	Customer Weight	Customer Rating	Concept 1	Concept 2	Concept 3	Concept 4
Efficient filtration system	50%	5	4	5	3	2
Accessible filter media replacement	50%	4	1	1	5	3
Periodic maintenance alert	50%	3	4	4	5	3
Increase system lifespan	50%	2	4	5	3	2
Better cost-benefit ratio	50%	1	2	1	4	4
Easy installation	30%	2	1	1	3	5
Have a competitive edge	20%	2	4	4	3	2
Rating			25	28	33	23

The proposed concept consists of a set of technologies already available on the market, integrated into a single system. The existence, especially outside Brazil, of similar systems that combine some of these technologies only reinforces the effectiveness of the methodology adopted in the product development.

The system was positioned after the water tank, considering that as indicated by [6] and [9] water tanks may still contain contaminating microorganisms.

Initially, a polypropylene filter was installed to remove suspended solids. This choice is supported by [10], who evaluated polypropylene filters and confirmed their effectiveness in water treatment. [11] used this type of filter for greywater treatment, also confirming its efficiency as a filtration medium.

Next, an activated carbon filter was included to remove chemical agents, as studies indicate that chlorine may be linked to the formation of trihalomethanes (THMs) in water [12]. [13] reinforces that chlorine-based disinfection can lead to THM generation and recommends activated carbon as an effective removal method.

For the disinfection system, the following alternatives were evaluated: ozonation, chlorination, and ultraviolet (UV) radiation. According to [14], UV radiation performed exceptionally well in disinfecting rainwater, completely eliminating total and thermotolerant coliforms. [15] adds that UV radiation is also effective in reducing coliform presence in water.

Compared to ozone treatment, [16] concluded that, under the investigated conditions, UV radiation showed higher efficacy in inactivating total and fecal coliforms.

As previously mentioned, issues related to chlorine use and controlling chlorination volume in residential systems may result in high THM formation levels. Therefore, this study opted for UV radiation disinfection. The UV lamp will only activate when water flow is detected.

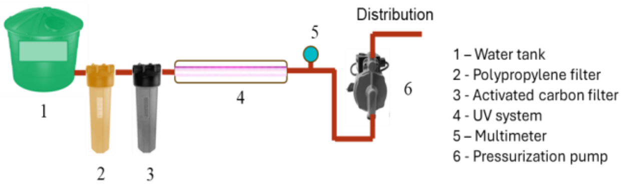
For the system's power supply, a combination of solar energy and utility power was considered, ensuring continuous 24 hour operation while minimizing energy costs.

In addition, a small pressurized pumping system will be used to ensure adequate pressure in the household plumbing, since, according to the Brazilian

Association of Technical Standards (ABNT), the minimum pressure required at the outlet of sanitary fixtures, such as showers and sinks, is 1 m.c.a [17].

A multiparameter monitor will also be installed to measure pH, turbidity, and dissolved oxygen, enabling a simple and effective verification of water quality. Figure 3 illustrates the chosen system.

Figure 3. Chosen system



4. Conclusion

Ensuring safe water consumption and avoiding health risks for users is of utmost importance, given that water, although essential for human intake, can also serve as a vehicle for disease transmission.

Faced with this challenge, the objective of this study was to apply the Quality Function Deployment (QFD) and Teoriya Resheniya Izobretatelskikh Zadach (TRIZ) methodologies in the search for an ideal water treatment system concept capable of minimizing health risks for families relying on residential water tanks.

The adopted methodologies proved effective in the development of a concept aligned with users' needs and requirements, as evidenced by a qualitative and quantitative analysis of the proposed concepts, in which Concept 3 achieved the highest score.

The application of the TRIZ method enabled specific improvements to be made to this concept, guided by defined inventive principles. The concept was subsequently reassessed with support from bibliographic references, which confirmed the consistency of the improvements implemented through TRIZ.

Despite these conceptual advancements, efficiency studies and sizing calculations are still required for a detailed evaluation of the system's performance and to validate its feasibility for residential use.

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