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Innovating Community-Based Drinking Water Treatment: A Mobile Device in Barangay Lupa, Compostela, Cebu

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Abstract:
In response to the significant issue of insufficient access to safe drinking water in the mountainous barangay of Lupa, Compostela, Cebu, this study provides a customized mobile water treatment device that seeks to address current drinking water issues, providing mitigation to the community. The treated water undergoes rigorous laboratory testing to determine the device's treatment performance on deep-well water sources in the barangay. This study evaluated the device's acceptability level, performance, and potential weaknesses using weighted mean calculations, microbial contamination calculations, and Failure Mode and Effects Analysis (FMEA). The results reveal a significant level of acceptance among respondents toward adopting the mobile water treatment device. Moreover, the device's treated water effectively meets the 2017 Philippine National Drinking Water Standards, making it safe for drinking. However, observation highlights device vulnerabilities, particularly the water pump's tendency to overheat and the UV sterilizer's sensitivity, emphasizing the importance of consistent monitoring and maintenance practices.

Keywords: Water treatment, mobile, filtration, disinfection, drinking water.

1. Introduction

1.1. Rationale of the Study

Water is necessary for life's survival. According to National Geographic, in 2021, water covers over 70% of the Earth's surface, but only 2.5% is freshwater. Access to clean drinking water is critical for human health and for properly developing agriculture, industry, and ecosystems. In recent years, ensuring access to clean water has become a significant concern. The twin concerns of rising population and climate change worsen the global water crisis. Globally, more than 1.1 billion people cannot access safe drinking water (Mishra et al., 2021). According to the statistics published in the UNESCO 2021, an estimated 829,000 people die each year as a result of diarrhea caused by contaminated drinking water, insufficient sanitation facilities, and poor hand hygiene habits. This figure comprises around 300,000 children under the age of five, or roughly 5.3% of all death cases in this age range.

According to the World Health Organization Philippines (2019), a significant proportion of the population, namely 19%, continues to have challenges in accessing safe drinking water. Additionally, a considerable portion of the population, amounting to 27%, persists in engaging in open defecation habits. Approximately 8 million individuals in the Philippines, predominantly residing in rural regions, lack access to drinking water. Remote areas typically need more clean and safe drinking water because centralized water treatment systems are impracticable and costly.

The municipality of Compostela Field Health Service Information System (FHSIS) 2022 Annual report stated that 207 households get their water supply and also drinking water from point sources, such as piped wells in barangay Lupa Compostela, Cebu, and 18 households from doubtful sources, such as open dug wells. This highlights the gaps in water access and quality throughout the community, emphasizing the need for further assessment and actions to provide safe and reliable water sources for all the residents.

Barangay Lupa, Compostela, Cebu, is located 12 km from the municipality's national road with an estimated elevation of 211.1 meters above mean sea level. The barangay shares a common border with three barangays of Compostela, that is Barangay Basak, Dapdap, Mulao, and two barangays of Danao City, that is Barangay Baliang and Manlayag. The population, as determined by the 2020 Census, was 1,053 individuals. This figure accounted for 1.88% of the overall population of Compostela (PhilAtlas, 2023). The barangay only has three deep wells as their water source, both for consumption and regular use. Consequently, the inhabitants are left with little alternative but to ingest water that has yet to undergo treatment, which could lead to significant health consequences.

Thus, this capstone study aims to build a community-centered approach to water treatment to enhance access to clean drinking water through mobile water treatment device. This capstone project assesses the device's acceptance in the community, its performance in treating water, and any potential weaknesses. Using technological innovation, the researchers seek to mitigate the community's pressing demand for safe and clean drinking water, effectively improving water quality and accessibility.

1.2. Statement of the Problem

The problem at hand is the lack of access to clean and safe drinking water in Barangay Lupa, a remote area of Compostela, Cebu. Because of its distance from urban areas, the residents find it difficult and expensive to obtain drinking water. Therefore, most of the residents rely on well water for all of their needs, including for consumption. Recognizing the difficulties, researchers evaluated the feasibility of introducing a mobile water treatment device to address the problem. The feasibility findings suggest that such a device is viable in all aspects, such as marketing, technical, operational, and financial aspects. Now, the focus shifts to the development and evaluation of the mobile water treatment device. Specifically, this capstone project seeks to answer the following:

- What is the level of acceptability of the local community in adopting the mobile water treatment device as an alternative drinking water source?
- Evaluate the effectiveness of the water treatment system and compare the quality of treated and untreated water according to the Philippine National Standards for Drinking Water 2017, in terms of:
  (a) bacteriological test, and
  (b) physical-chemical laboratory test?
- What are the failure modes of the major components of the prototype in a given period in terms of:
  (a) water pump,
  (b) water filter, and
  (c) UV sterilizer?

1.3. Objectives of the Study

This study aims to comprehensively evaluate the mobile water treatment device in Barangay Lupa, Compostela, Cebu, to improve access to safe and clean drinking water. This study specifically seeks to accomplish the following goals:

- To achieve an acceptability level in the local community of between 4 to 5 weighted means for the mobile water treatment device as an alternative drinking water source.
- To test the untreated and treated water in terms of bacteriological and physical-chemical laboratory tests. Ensuring that the treated water “Passed” all the parameters such as total coliform, thermotolerant coliform, arsenic, cadmium, lead, turbidity, pH, apparent color, TDS (Total Dissolved Solids), nitrate, and residual chlorine transparent in the bacteriological and physical-chemical test in accordance with the 2017 Philippine National Drinking Water Standards.
- To provide a robust foundation of the prototype’s failure modes considering the three major components, the water pump, filter, and Ultraviolet (UV) Sterilizer.

1.4. Significance of the Study

This study will benefit the following:

• Residents of Barangay Lupa. This study provides access to safe drinking water and contributes to improving public health in the community.
• Local Government Units (LGU). This study provides guidance in investing in mobile water-treatment devices for residents with limited access to safe and clean drinking water.
• Non-Governmental Organizations (NGOs). The study provides practical insights into the specific needs and challenges faced by communities in Barangay Lupa.
• Department of Health (DOH). The study provides additional information about the improvement of public health in the community, reducing waterborne illnesses and associated health risks.
• Philippine government and regulatory bodies. The study provides government initiatives to enhance water accessibility and safety, contributing to policy and regulations for deploying water treatment technologies in remote areas.
• Sustainable Development Goals (SDG). Addressing the issues of water treatment and contamination, this research immediately contributes to worldwide efforts to ensure everyone has access to safe and clean drinking water, supporting health, well-being, and sustainable development.
• Future researchers. The study may provide future references and contributions for its improvement.

1.5. Limitation of the Study

The limitation of this study is its reliance on laboratory-based observations and experiments, which might not fully represent the real-world challenges and conditions encountered during the deployment and operation of the mobile water treatment device in various environmental contexts. Furthermore, considering this device is still in its infant stage, its efficiency may not match that of established water treatment systems currently available in the market. As with many new technologies, optimization over time is critical for improving performance and dependability.

2. Materials and methods

2.1. Research Design

This capstone project utilizes a mixed-methods approach, combining qualitative and quantitative methodologies, to address the issues of clean water availability in Lupa, Compostela, Cebu. Following the full assessment, which validated the viability of installing the mobile water treatment device, the study proceeds to the prototyping and evaluation phase of the device. Qualitative and quantitative methods, such as surveys and interviews, are used to determine the level of acceptability of the local community in adopting the mobile water treatment device as an alternative drinking water source. Moreover, this mixed-methods approach will also be used to assess the water laboratory test results of the untreated and treated water. In addition, the same research designs are also incorporated in the observation of the device's vulnerabilities. Thus, this multimodal approach ensures a thorough understanding of the project aim and provides valuable insights into improving the drinking water access and quality in Barangay Lupa, Compostela, Cebu.

2.2. Research Process Flow

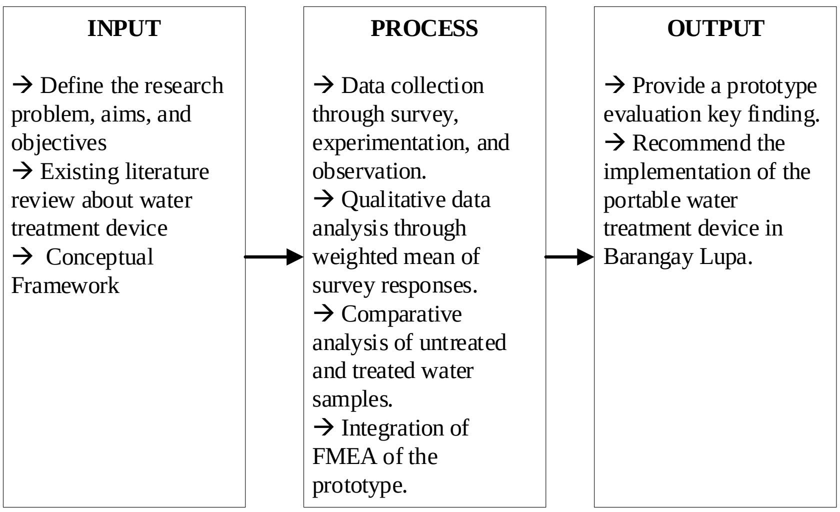

Figure 1: Process Flow of the Study

A thorough research process flow has been methodically developed to address the crucial issue of insufficient access to clean and safe drinking water in Barangay Lupa, Compostela, Cebu. This research project is directed by a structured methodology that aims to systematically unravel the complexities of insufficient sources of clean drinking water and devise feasible solutions. At its core, the research process flow is a strategic roadmap for moving through data gathering, analysis, and recommendation stages. Every section, from problem identification to research objective development, data collection and analysis, and result interpretation, is methodically orchestrated to create rigorous and coherent research.

2.3. Data Collection and Analysis Methods

The data gathering methods utilized in this study are survey, interview, and experimentation.

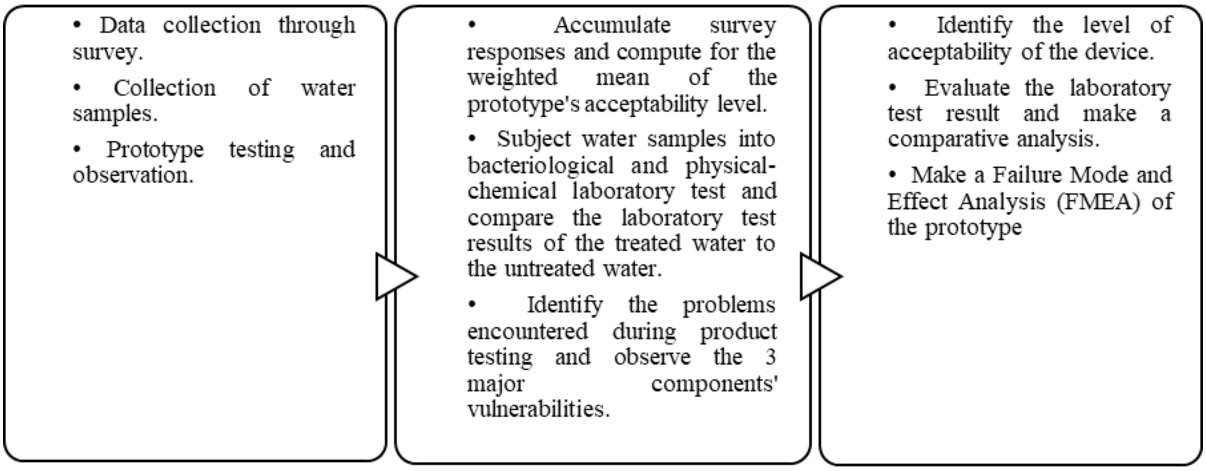

Figure 2: Data Collection and Analysis Procedure

Survey and Interview. This method entails the systematic collection of data to determine the respondents' levels of acceptance of the mobile water treatment device. Structured questionnaires with both open- and closed-ended questions were used to collect relevant information. Additionally, a 5-point Likert scale was used to objectively assess the device's level of acceptance among respondents. Statistical techniques such as weighted mean are employed to summarize the Likert scale data, offering a concise representation of the overall acceptance level.

Table 1: 5-point Likert Scale Scoring Procedure

Scale	Range	Description
1	1.00-1.80	Very Poor
2	1.81-2.60	Poor
3	2.61-3.40	Fair
4	3.41-4.20	Good
5	4.21-5.00	Very Good

Experiment. During the experimental phase, researchers examined well water trends in the barangay by evaluating water samples from a deep well over three months. The untreated water was tested for bacteriology and physical-chemical tests, followed by the same tests on treated water with a mobile water treatment system. Results were compared to set standard levels; if exceeded, the sample was classified as a failure in that parameter, suggesting contamination. In contrast, passing results indicated that the treatment had been successful. These tests were administered at various periods, allowing for strategic actions based on the results. For example, if contamination was identified, interventions such as adding a chlorinator may be taken to improve filtration efficacy. This approach gave valuable insights into the water treatment process, allowing for more informed judgments about future upgrades or interventions.

The device's water treatment process as shown in figure 3 includes several steps for thorough filtration. It starts with a polypropylene filter to remove bigger particles, followed by a Granular Activated Carbon (GAC) filter, which removes organic compounds and contaminants that affect taste and odor. Next, a Chlorine, Taste, and Odor (CTO) filter improves the water by removing pollutants such as lead and cysts. Finally, the water is UV sterilized, which uses ultraviolet light to neutralize and eliminate pathogens, ensuring that the water is safe and meets high-quality drinking standards.

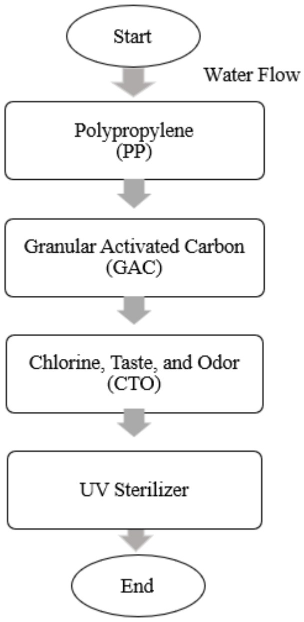

Figure 3: Water Treatment System Flow

Observation. The researchers conducted product testing and observation to rigorously assess the failure modes of the prototype. The evaluation focused on the core components - the pump, filter, and UV sterilizer and examined aspects that could affect their durability and overall performance of the water treatment process. After the observation, a Failure Mode and Effects Analysis (FMEA) is integrated to evaluate the problems encountered during the product testing. This systematic approach allows the researchers to meticulously assess the issues observed throughout the product testing phase, revealing potential vulnerabilities and areas for improvement in the prototype design.

2.4. Treatment of Data

The information gathered was assessed and scrutinized using quantitative and qualitative tools to determine the precise interpretation of the results. Matrix tables were made to organize, summarize, and analyze the data gathered so that the data could be understood easily. The following tools were used in the analysis of data:

- Weighted Mean – This is used to interpret the perception of the respondents and the level of acceptability of installing a mobile water treatment device.
- Rate of Change in Microbial Contamination Calculation – This mathematical process is an important tool in assessing the dynamics of microbial contamination in the mobile water treatment device process.
- Failure Mode and Effects Analysis (FMEA) – This is used to assess the mobile water treatment device in terms of the identified potential failure modes of every material used and their consequences on the device's functionality.

2.5. Sampling Technique

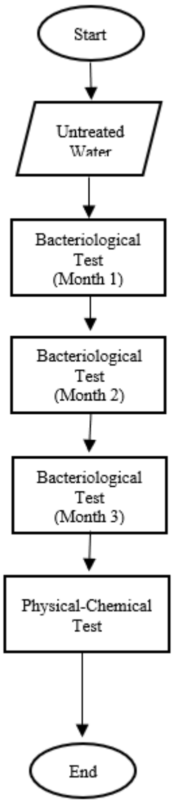

Figure 4: Untreated Water Sampling Method Process Flow

Using bacteriological water laboratory testing, the researchers evaluated untreated water samples for three months, from November 2023 to January 2024. During this time, three bacteriological water tests were conducted, all of which produced failed results suggesting the presence of contaminants. Following these initial assessments, the untreated water was subjected to a physical-chemical water test in January to determine all of the minerals and compounds present in the water, identify potential contamination sources, and assess overall water quality.

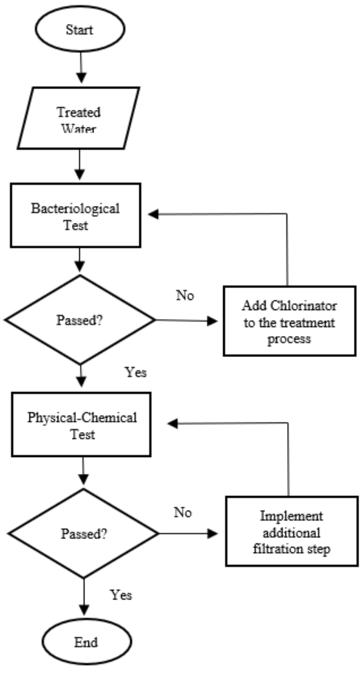

Figure 5: Treated Water Sampling Method Process Flow

Following data collection from the bacteriological and physical-chemical water tests, the researchers treated the untreated well water by subjecting it to filtration in the mobile water treatment device. The treated water was then tested bacteriologically to ensure the treatment technique effectively eliminated harmful bacteria.

Once the treated water successfully passed the bacteriological test, it underwent a physical-chemical water test to ensure the comprehensive removal of minerals and compounds.

Finally, all the collected data and test results were interpreted for a comprehensive analysis, providing valuable insights into the quality and safety of the water source.

2.6. Modeling and Analysis of Contaminant Removal in Water Treatment System: Integrating Filtration and UV Treatment

Water treatment systems are vital in providing safe and clean drinking water. One promising approach is the combination of filtration and UV treatment. Filtration physically eliminates impurities, and UV radiation effectively disinfects, resulting in a practical approach for dealing with microbiological contamination.

In this integrated system, knowing the dynamics of pollutant removal is critical. This can be done by using mass balance modeling to quantify the flow and distribution of contaminants and kinetic models to explain the contaminant removal rate. Using mass balance principles, researchers may track changes in contaminant concentrations over time, offering insights into the system's performance and efficiency in pollutant removal. Kinetic models explain how contaminants are removed and disinfected in the context of filtration and UV treatment. These models maximize treatment methods and successfully inform the design of improved water treatment systems by incorporating elements such as rate constants, reaction kinetics, contact duration, and system geometry to reduce contaminant concentrations over time. By combining these models, researchers can create a comprehensive framework for optimizing water treatment device performance and producing safe and clean drinking water.

Integrating filtration and UV treatment methods provides mutually beneficial advantages by combining filtration's physical removal capabilities with UV radiation's disinfection qualities. This integration offers a robust and dependable solution for treating microbiological contamination in water treatment devices, ensuring the production of safe and drinkable water for various applications. Thus, in order to compute the rate of change of microbial contaminant concentration over time using the combination of filter and UV sterilizer, the formula below is used:

$$\frac{dC}{dt} = -(k_f + k_{UV}) \cdot C \qquad (1)$$

where, $\frac{dC}{dt}$ is the rate of change of microbial contaminants concentration over time, k_f is the filtration constant, k_{UV} is the UV treatment rate constant, and C is the concentration of microbial contaminants such as bacteria or viruses per unit volume of water. However, in this study, the available data is only the combined reduction of microbial contaminants measured through bacteriological laboratory tests. Hence, the effective combined rate of change of the microbial contaminants concentration of the filter and UV sterilizer can still be measured using this formula:

$$\frac{dC}{dt} = -k_{combined} \cdot C \qquad (2)$$

where, $\frac{dC}{dt}$ is the rate of change of microbial contaminants concentration over time, $k_{combined}$ is the combined rate constant (units: per time) representing the rate at which the concentration of microbial contaminants decreases due to the combined filtration and UV treatment process, and C is the concentration of microbial contaminants such as bacteria or viruses per unit volume of water. The combined rate constant provides a measure of the effectiveness of the entire treatment process, taking into account both filtration and UV treatment. Before solving the whole equation, compute first the overall reduction in microbial concentration using the formula:

$$\boldsymbol{k_{combined} = -\frac{1}{t} \cdot ln\left(\frac{C(t)}{C_o}\right)} \qquad (3)$$

where, $k_{combined}$ is the combined rate of filter and UV sterilizer (units: per time), t is the time elapsed, $C(t)$ is the concentration of microbial contaminants (unit: number of microorganisms per unit volume) at $t = 0$, and C_o is the initial concentration of microbial contaminants that can be obtained in the laboratory test result.

After obtaining the value of $k_{combined}$, there is a need to solve for C to get the concentration of contaminants in the water. Equation 1 is used to derive the formula to get the value of C.

$$\boldsymbol{C = C_0 \cdot e^{-k_{combined} \cdot t}} \qquad (4)$$

wherein this equation represents the exponential decay of microbial contaminants over time as a result of the combined filtration and UV treatment process.

2.7. Technical Design Specifications

The development of the production process for the mobile water treatment device necessitates a combination of accuracy, productivity, and quality assurance. The process commences with procuring materials from dependable vendors for various components, including alkaline filtering systems, UV sterilizers, water booster pumps, and other necessary components. The subsequent phase entails the preparation and integration of components, commencing with the structural elements, such as the water container and tubing, and culminating in the incorporation of the water booster pump. This technique involves incorporating the UV sterilizer and faucet into the three-phase filtering system. Inspections for quality control and leak testing are carried out at different stages of assembly to guarantee secure connections and avoid any water leakage. Electrical wiring and testing are conducted to incorporate pumps and UV sterilizers, ensuring optimal operation and safety. The final assembly entails a thorough quality inspection, which includes accessories and instructional materials. The process undergoes continuous refining through real-world usage, tests, and validations.

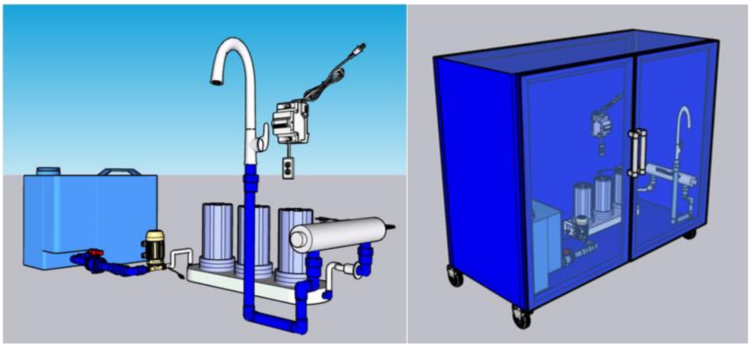

Figure 6: Internal and External Projection of Mobile Water Treatment Device

The mobile water treatment device is notable for its distinctive features in terms of both the treatment process and its ability to be easily transported, as shown in Figure 6. The device employs two primary methods: filtration and disinfection. The filtration process consists of three stages. The first stage involves the use of a Polypropylene (PP) filter, which effectively removes larger particles and sediments. The second stage utilizes a Granular Activated Carbon (GAC) filter, which is highly efficient in eliminating organic compounds and pollutants that can affect the taste and odor of the water. The final stage involves the use of a Chlorine, Taste, and Odor (CTO) filter, which further refines the process and enhances the overall quality of the water. Furthermore, UV sterilizers employ ultraviolet radiation to deactivate and eliminate microorganisms, effectively neutralizing their detrimental impact.

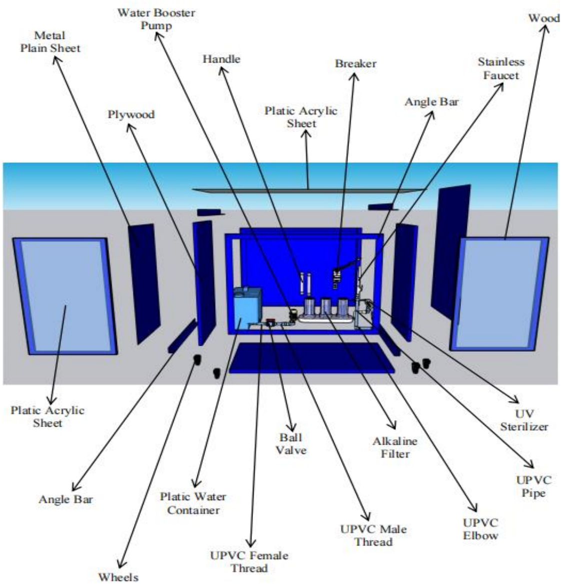

Figure 7: Exploded Diagram of Mobile Water Treatment Device

Figure 7 presents the exploded diagram of the mobile water treatment device. This illustrates a detailed and comprehensive visualization of the overall device's components. Based on the picture above, the upper portion from the left to right perspective includes the plain sheet, plywood, water booster pump, handle, acrylic sheet, angle bar, stainless filter faucet, and wood. Meanwhile, the acrylic sheet, angle bar, wheels, plastic water container, UPVC female adaptor with thread, ball valve, UPVC male adaptor with thread, alkaline filter, UPVC elbow, UPVC pipe, and UV sterilizer are situated at the lower portion from left to right perspective. By visually deconstructing each component and emphasizing their interdependence, the diagram reveals a profound understanding of the system's functionality.

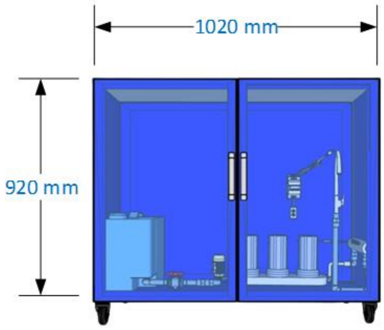

Figure 8: 2D Front Projection of the Device

Figure 8 shows the device's dimensions and design in a 2D front projection. The device's physical dimensions are depicted in full in the figure, which highlights its 920 mm length and 1020 mm width.

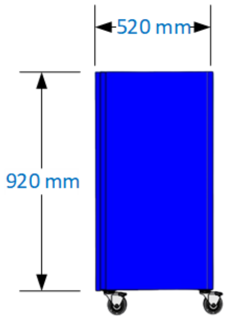

Figure 9: 2D Side Projection of the Device

A two-dimensional side projection of the device is shown in Figure 10, giving a thorough visual depiction of its size and arrangement. The device's compact and streamlined design is illustrated by the device's 520mm width and 920mm length, as shown in the figure.

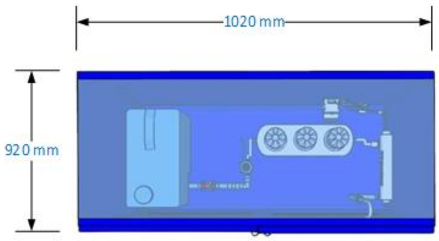

Figure 10: 2D Top Projection of the Device

A two-dimensional top projection of the device is shown in Figure 10, providing a thorough overview of its configuration and measurements from above. The device's width (1020 mm) and length (920 mm) are shown in the figure, which also makes its total dimension and rectangular shape evident.

2.8. Water Treatment Device Process

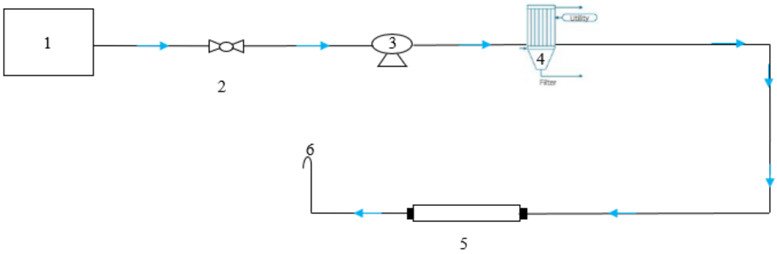

Figure 11: Water Treatment Device Process

Legend:

1 – Raw water storage; 2 – UPVC ball valve; 3 – Water pump; 4 – Alkaline Filtration; 5 – UV Sterilizer; 6 – Product water outlet

The well-defined water treatment process, starting from the raw water storage and progressing logically through each stage, contributes to the device's ease of use. The inclusion of a water booster pump facilitates the efficient transfer of water through the filtration system, ensuring a seamless flow. The three-stage filtration process involving Polypropylene (PP), Granular Activated Carbon (GAC), and Chlorine, Taste, and Odor (CTO) demonstrates a commitment to thorough water filtration.

The incorporation of a UV sterilizer adds an extra layer of assurance, effectively eliminating microorganisms and further enhancing the device's credibility in providing clean and safe drinking water. The clarity in the process, from the raw water source to the faucet of the mobile water treatment device, ensures transparency and builds user trust in the efficacy of the water treatment.

3. Results and discussion

This section provides a structured overview of the research findings, organized chronologically according to the problems indicated in the problem statement. A systematic approach to each problem statement provides insights generated from the findings, improving knowledge of the study findings and their value in the area.

Level of Acceptability of the Mobile Water Treatment Device

Table 2: The Level of Acceptability of the Local Community to Adopt the Mobile Water Treatment Device as an Alternative Drinking Water Source

Empathy Map	Overall Weighted Mean	Description
Think and Feel	4.52	Very Good
Do	4.5	Very Good
Hear	4.87	Very Good
Say	4.63	Very Good
Average	4.63	Very Good

The comprehensive analysis of the survey data, as framed within the empathy map, demonstrates a profound understanding of the target respondent's cognitive and emotional aspects of the given design prototype of the mobile water treatment device.

The table provides valuable information about the level of acceptability among target respondents in using mobile water treatment devices in their households. The researchers efficiently assessed the respondents' attitudes and perceptions using the computed total weighted mean scores across the various aspects of the empathy map (think, feel, do, hear, and say). Notably, all areas of the empathy map obtained ratings in the "Very Good" category, ranging from 4.5 to 4.87, indicating a high level of acceptance.

The consistently satisfactory ratings across all areas show a widespread positive response to the mobile water treatment device. The weighted mean score of 4.87 for "Hear" indicates that the community is very open to receiving information or feedback about the device's benefits, which could indicate strong word-of-mouth recommendations or positive testimonies from reliable sources. Also, this shows that the respondents are very aware of the existence of water treatment and its benefits. Furthermore, the ratings for "Think and Feel," "Do," and "Say" suggest a group tendency to embrace the proposed solution, indicating a solid propensity among respondents to consider and implement the device in their households.

The high level of acceptability demonstrates the potential effectiveness of the mobile water treatment device in resolving the community's water-related concerns. It shows that the device is well-suited to the target respondents' tastes, needs, and priorities, indicating a bright future for its acceptance and implementation. Furthermore, the findings underscore the significance of clear communication and education campaigns to raise knowledge and comprehension of the device's benefits, allowing for its successful integration into community households in the future.

This comprehensive approach of using an empathy map to know the level of acceptability of the respondents demonstrates the depth of insight gained, and it serves as a firm foundation for the researchers to establish a prototype that is deeply relevant to the respondents' needs and preferences. In fact, according to (Dam & Siang, 2024), an empathy map is helpful in design thinking and product development. By delving into the user's thoughts, feelings, words, and actions, these maps offer a holistic view of the user's experience.

Effectiveness of the Mobile Water Treatment Device and Comparison of the Water Laboratory Test Results of Untreated and Treated Water

This section discusses the water test results of the untreated and treated well water of Barangay Lupa, Compostela, Cebu. The tests are bacteriological, physical, and chemical tests conducted at Talisay Water Lab located in Talisay City, Cebu. According to The Philippine National Standards for Drinking Water of 2017, the mandatory drinking water quality parameters include the thermotolerant coliform, e. coli, arsenic, cadmium, lead, nitrate, color, turbidity, pH, total dissolved solids, and disinfectant residuals. These parameters were measured, tabulated, and analyzed.

Table 3: Bacteriological Water Test Results of Untreated Well-Water

Parameters	UoM	Standard	November 2023		December 2023		January 2024	
			Result	Remarks	Result	Remarks	Result	Remarks
Total Coliform	MPN/ 100mL	<1.1	>8.0	Failed	>8.0	Failed	>8.0	Failed
Thermotolerant Coliform	MPN/ 100mL	<1.1	>8.0	Failed	>8.0	Failed	8	Failed

**UoM=Unit of Measurement*
**MPN=Most Probable Number*

Table 3 presents the bacteriological test results of untreated well water from November 2023 to January 2024. The results show a consistency of greater than 8 MPN/100mL of water for the total coliform from the standard of less than 1.1 MPN. Potable water must contain less than 1.1, the most probable number of coliforms in 100 mL of water, to make it safe for consumption. Detecting total coliform bacteria in potable water may indicate the existence of contaminants, such as the more dangerous E. coli pathogens. Frequently, contamination results from runoff and flooding that carries human and animal refuse. Since these bacteria are tasteless, odorless, and colorless, laboratory analysis is the only method to detect them in water (Schuerman, 2021).

In addition, the tabulated results also show greater than 8 MPN/100mL of water for the thermotolerant coliform during the months of November and December 2023. In January 2024, the number of thermotolerant coliforms in 100 mL water declined to 8. Even if there is a decrease in its MPN, it failed from the standard of less than 1.1 MPN, the same as the total coliform. Thermotolerant E. coli is a crucial bacterium present in fecal coliforms and serves as a dependable marker for fecal contamination. Unlike any other bacteria that originated in the environment, thermotolerant E. coli is primarily present in the feces of people and warm-blooded animals (Hammad et al., 2022).

Table 4: Bacteriological Water Test Results of Untreated and Treated Well-Water

Parameters	UoM	Standard	Treated Well Water	
			Result	Remarks
Total Coliform	MPN/ 100mL	<1.1	<1.1	Passed
Thermotolerant Coliform	MPN/ 100mL	<1.1	<1.1	Passed

**UoM=Unit of Measurement* **MPN=Most Probable Number*

Table 4 presents the bacteriological water test results of treated well water. Another bacteriological test taken on January 2024 for the treated water shows less than 1.1 MPN per 100 mL of water sample, which is marked as passed from the standard of less than 1.1 MPN of both parameters.

The laboratory test results are used to calculate the rate of change in microbiological contamination within the water treatment system. This analysis allows for the evaluation of the system's performance in reducing microbial presence and offers information about the device's treatment efficiency. The effective combined rate of change of the microbial contaminants concentration of the filter and UV sterilizer over time can be solved using equation 2. However, it is necessary to solve for the combined rate constant of the filter and UV sterilizer and the value concentration of contaminants in the water using equations 3 and 4, respectively. Using equation 3, compute first the combined rate constant of the filter and UV sterilizer with respect to the following value: t =1 minute, C(t)=1.1 MPN/100mL, and C_o= 8 MPN/100mL.

$$k_{combined} = -\frac{1}{t} \cdot \ln(\frac{C(t)}{C_o})$$

$$k_{combined} = -\frac{1}{1} \cdot \ln(\frac{1.1}{8})$$

$$k_{combined} = -\ln(0.1375)$$

$$k_{combined} = -(-1.98100146886)\ (taking\ the\ natural\ algorithm\ of\ 0.1375)$$

$$k_{combined} = 1.98100146886\ /\text{min}$$

$$k_{\text{combined}} = 1.981\ /\text{min}$$

This value represents the rate at which the concentration of contaminants decreases per minute as water passes through a combined filtration and UV treatment process. Next, solve the value concentration of contaminants in the water (C) using equation 4 with respect to the following values: C_o = 8 MPN/mL, $k_{combined}$ = 1.98100146886/min, and t = 1 min.

$$C = C_0 \cdot e^{-k_{combined} \cdot t}$$

$$C = 8 \cdot e^{-1.98100146886-1}$$

$$C = 8 \cdot e^{-1.98100146886}$$

$$C = 8 \cdot 0.138417038821$$

$$C = 1.10733630656\ \text{MPN/100mL}$$

$C = 1.107\ \text{MPN/100mL}$ or 1.107 ppm

so, it means that after 1 minute of combined filtration and UV treatment, the concentration of microbial contaminants is approximately 1.107 MPN/100mL or simply 1.107 ppm since MPN/100mL is equivalent to 1ppm. This means that the treatment method substantially lowered the microbial contamination level from the initial concentration of 8 ppm to roughly 1.107 ppm, demonstrating the efficacy of the filtering and UV treatment in significantly reducing microbial contaminants. After obtaining the value of k_{combined} and C, the computation can now proceed in solving the rate of change of the concentration of the microbial contaminant over time using equation 2.

$$\frac{dC}{dt} = -k_{combined} \cdot C$$

$$\frac{dC}{dt} = (-1.98100146886)(1.10733630656)$$

$$\frac{dc}{dt} = -2.200\ \text{ppm/min}$$

The negative rate of change, measured at -2.200 ppm/min, suggests a decrease in the concentration of contaminants over time, consistent with the intended goal of water treatment processes that strive to reduce contaminant levels. This magnitude represents the rate at which the contaminants concentration is decreasing, with a greater absolute value meaning a faster reduction in contaminants concentration, indicating improved treatment efficiency. This rate of change highlights the treatment process's success. It serves as an essential parameter for evaluating treatment efficacy and the capacity of the mobile water treatment device to reduce pollutant levels in water

Table 5: Comparison of the Bacteriological Water Test Results of Untreated and Treated Well-Water

Parameters	UoM	Standard	Untreated Well Water		Treated Well Water	
			Result	Remarks	Result	Remarks
Total Coliform	MPN/ 100mL	<1.1	>8.0	Failed	<1.1	Passed
Thermotolerant Coliform	MPN/ 100mL	<1.1	>8.0	Failed	<1.1	Passed

**UoM=Unit of Measurement *MPN=Most Probable Number*

Table 5 presents the comparison of the bacteriological water test results of untreated and treated well water. The data presented in the untreated water are the average results taken for three consecutive months, as shown in Table 12, which provides a mean of greater than 8.0 MPN per 100 mL of water sample for the total coliform and thermotolerant coliform. Another bacteriological test taken on January 2024 for the treated water shows less than 1.1 MPN per 100 mL of water sample, which is marked as passed from the standard of less than 1.1 MPN of both parameters. This proves that the mobile water treatment device has been effective in treating and removing the coliforms of the well water in Barangay Lupa, Compostela, Cebu, which is also supported by the microbial contamination reduction calculation.

Table 6: Physical and Chemical Water Test Results of Untreated and Treated Well-Water

Parameters	MAL	Untreated Well Water		Treated Well Water	
		Result	Remarks	Result	Remarks
Arsenic	0.01 ppm	<0.001 ppm	Passed	<0.001 ppm	Passed
Cadmium	0.003 ppm	<0.0006 ppm	Passed	<0.0006 ppm	Passed
Lead	0.01 ppm	<0.001 ppm	Passed	<0.001 ppm	Passed
Turbidity	5 NTU	1 NTU	Passed	0.1 NTU	Passed
pH	6.5-8.5	6.94	Passed	7.2	Passed
Apparent Color	10 CU	1 CU	Passed	1 CU	Passed
TDS (Total Dissolved Solids)	600 ppm	526 ppm	Passed	478 ppm	Passed
Nitrate	50.00 ppm	0.04 ppm	Passed	<0.01 ppm	Passed
Residual Chlorine	0.3-1.5 ppm	<0.01 ppm	Passed	<0.01 ppm	Passed

**MAL=Maximum Allowable Level*

Table 6 reveals the results of the physical and chemical water tests for both untreated and treated well-water of Barangay Lupa. The results show that the untreated well water passed all the parameters for the physical and chemical tests. In terms of physical-chemical water quality parameters, including arsenic, cadmium, lead, turbidity, pH, apparent color, total dissolved particulates, nitrate, and residual chlorine, deep well water may satisfy maximum allowable levels. This is because deep well water is filtered naturally by rock and soil strata, thereby facilitating the elimination of impurities and contaminants. The mineral composition, wave velocity, density, and porosity of deep rock are all factors that influence the purity of water extracted from deep wells (Sitaram, 2022). Additionally, geological factors in the studied area, such as the presence of bicarbonates, which contribute to water hardness, can affect the physicochemical parameters of well water (Reena at al., 2022).

Furthermore, the treated well water also passed all the maximum allowable levels (MAL) of the parameters for physical and chemical tests. Both untreated and treated well-water have the same results for arsenic, cadmium, lead, apparent color, and residual chlorine having <0.001 ppm, <0.0006 ppm, <0.001 ppm, 1 CU, <0.01 ppm from the maximum allowable level of 0.01 ppm, 0.003 ppm, 0.01 ppm, 10 CU, 0.3-1.5 ppm, respectively. Turbidity decreases from 1 NTU to 0.1 NTU. The pH increased from 6.94 to 7.2, but both still passed the MAL of 6.5-8.5. The total dissolved solids (TDS) decrease from 526 ppm to 478 ppm, and the nitrate reduces from 0.04 ppm to <0.01 ppm. These results from the treated well water signify that the mobile water treatment device can also improve the physical and chemical properties of the well water of Barangay Lupa, Compostela, Cebu.

Failure Modes of the Major Components of the Prototype

Table 7: Water Treatment Device Performance Analysis and Observations

Cycle No.	Time	Weather Temperature °C	Water Pump Temperature °C		UV Sterilizer Temperature °C		UV Sterilizer Ballast Color	Filter Cartridge Color			Other Observation
			Before	After	Before	After		1st Stage (PP)	2nd Stage (GAC)	3rd Stage (CTO)	
1	09:15 am-12:15 pm	30	30	85.8	29.7	35	Green	Orange	White	Brown	There's a major leakage from the UV sterilizer and the elbow between the pump and filter that causes electric shock.
2	01:50 pm-04:50 pm	31	31	95	30.5	36.8	Green	Orange	White	Brown	After mitigation, the elbow between the pump and filter still leaking but only minimal.
3	09:16 am-12:16 pm	29	29	86	29.2	34	Green	Orange	White	Brown	If the filter will be drained, let it function for 1 minute for storing before turning the faucet on.
4	01:46 pm-4:46 pm	31	31	98	30	35.4	Green	Orange	White	Brown	There's a leakage that causes electric shock to pump booster, faucet, frame and door lock.
5	09:30 am-12:30 pm	31	31	95.4	32.5	37.7	Green	Orange	White	Brown	Chlorine odor is dominant, and there's a small leaking in the first elbow, from pump to filter after 30 mins. of using.
6	2:00 pm-5:00 pm	32	33.4	101	31.7	37	Green	Orange	White	Brown	The body of the pump is hotter than the head. There's a drop of temperature if wind occurs.
7	10:42 am-01:42 pm	31	30.8	103	30.2	35.8	Green	Orange	White	Brown	Minimal leaking occurs.
8	3:00 pm-06:00 pm	31	30	101	32	39.7	Green	Orange	White	Brown	Minimal leaking still occurs but in small drops.
9	09:50 pm-12:50 pm	31	27.1	106	28.7	33.5	Green	Orange	White	Black	There's a very minimal leaking, from pump to filter.
10	2:34 pm-05 pm	29	33.6	84	29.5	35.4	Green	Orange	White	Black	No leaking even no mitigation is applied.

This table comprehensively evaluates the performance and observations made by a water treatment system over ten cycles. Each cycle includes extensive information about time, weather temperature, water pump temperature, UV sterilizer temperature, UV sterilizer's ballast color, filter cartridge color, and other noteworthy observations. This analysis attempts to provide insights into the operating efficiency, challenges, and opportunities for improvement in the water treatment device by systematically documenting these characteristics. The observation highlights the three main components: the water booster pump, alkaline filter, and UV sterilizer.

Water Booster Pump. Analyzing the temperature data for the water booster pump gives some interesting insights into its thermal behavior and the operational considerations related to the water treatment system. The temperature of the water pump varies over time and is impacted by factors such as surrounding temperature and operational conditions. Throughout the recorded cycles, the water pump's temperature is generally consistent with the environmental temperature, demonstrating the system's response to external thermal fluctuations. For example, in Cycles 1 and 2, where environmental temperatures are comparatively moderate at 30°C and 31°C, the water pump temperatures are recorded at 85.8°C and 95°C, respectively, suggesting a proportional reaction to environmental conditions.

However, deviations from this trend have been noted in some cycles, indicating probable anomalies or operational issues. Notably, in Cycle No. 6, despite the environmental temperature of 32°C, the water pump temperature rises significantly to 101°C, indicating potential overheating or inefficiencies in thermal regulation devices. Similarly, in Cycle No. 10, where the ambient temperature is 29°C, the water pump temperature drops to 84°C, indicating probable changes in operational conditions or system performance. According to the recommendations provided by SL Power Electronics (2019), it is essential to keep pump temperatures below 105 degrees Celsius in order to decrease the probability of system failures occurring. The overheating problem can be mitigated if there is a temperature sensor in the water pump to deactivate the water pump when it reaches the device's upper limit temperature, ensuring efficient performance and preventing any overheating damage, which is not yet adapted in this mobile device. Moreover, it is also important to note that the gallon or untreated water storage must not run out of water, as it will damage the water pump.

Furthermore, observations of leaking incidents involving the water pump in several cycles raise questions about system integrity and safety. For example, in Cycles 1 and 4, major leakage problems cause electric shock dangers, underlining the significance of early detection and mitigation of such issues to ensure operational safety and system reliability.

Overall, the study emphasizes the importance of monitoring and maintaining the water booster pump's temperature inside the water treatment system. Understanding the factors influencing its thermal behavior and dealing with operational challenges like leakage occurrences are critical for improving system performance, guaranteeing operational safety, and sustaining water quality standards. Additional investigation and remedial actions may be required to address reported abnormalities and improve the overall efficiency and dependability of the water treatment system.

Alkaline Filter. Analyzing the color variations of the filter cartridges across ten cycles provides vital information about the water treatment device's effectiveness and possible risks. Throughout all cycles, the second-stage (GAC) and third-stage (CTO) filter cartridges retain their original white color, indicating effective retention of filtration qualities and ongoing impurity removal. However, the first stage (PP) filter cartridge appears to be in color orange, indicating constant efficacy in absorbing bigger particles and sediments. The persistent color may indicate that the PP filter is functioning properly, but it could also indicate particulate matter buildup, which is demanding maintenance. The color changes of the filter cartridge could also be due to continuous use of the device. Regular maintenance and inspection of the filtration system and preventative measures are required to ensure optimal efficiency and water quality. In conclusion, monitoring filter cartridge colors aids in identifying potential sources of pollution and motivates timely maintenance activities to maintain the effectiveness of the water treatment process.

UV Sterilizer. Based on the observation data, the UV sterilizer system maintains a consistent temperature range throughout the ten observed cycles. The UV sterilizer temperature remains steady between 33.5°C and 39.7°C, demonstrating the system's robust functionality. These slight temperature variations are most likely the result of external effects such as changes in ambient temperature and minor system modifications. The recorded UV sterilizer temperature is within the permitted working range defined by the manufacturer, as seen on the Wabi website. This emphasizes the importance of external factors in determining system performance during operation.

Throughout the observation period, the UV sterilizer ballast remains a steady green color, indicating that the UV lamps are properly operating and activated. The green appearance of UV ballast light indicates a reliable power supply to the UV lamps, ensuring successful water sterilization. The absence of color anomalies or variations shows no serious failures or problems in the UV sterilization system. In contrast, the red color in the UV ballast indicates a malfunction, and immediate attention is needed to resolve the issue and maintain treatment efficacy.

The UV sterilizer temperature and ballast color are consistent and reliable, demonstrating the UV sterilization process's efficacy in upholding water quality standards. According to the specifications on the Wabi website, the UV sterilizer operates typically between 22.3 and 32.2°C, with a maximum threshold of 54.4°C, emphasizing the impact of external influences on system performance. Continuous monitoring and maintenance are required to ensure optimal performance and minimize potential disturbances in the UV treatment process. Routine inspections and calibration of UV sterilization equipment are critical steps in ensuring consistent performance and adherence to severe water safety procedures.

In summary, the overall observation of the water treatment system over ten cycles yield significant findings. The leakage at the elbow linking the pump to the filter is the most common problem during device testing. Despite mitigation efforts in Cycle No. 2 to address the issue, such as applying sealant to secure the leaking, the problem persists and remains unresolved. Subsequent cycles show negligible leaking from the pump, indicating a continuing vulnerability that requires care to avoid potential system failures. Notably, Cycle No. 9 shows minor leaking, emphasizing the issue's endurance. However, a good development can be observed in Cycle No. 10, where the leaking is stated to have been resolved, demonstrating progress in treating the long-standing issue. The mitigation strategy employed in this cycle involved applying sealant and then allowing it to dry before usage. This approach differs from past mitigating attempts. Despite the changes, the continuance of leaking in the previous cycles indicates a potential issue caused by using the device before the sealant fully dries. This emphasizes the need to provide enough time for the adhesive to dry completely to resolve the leakage issue effectively. Addressing these underlying reasons through comprehensive maintenance and repair processes is critical to preventing further leaks and ensuring the water pump's reliability within the treatment system.

Table 8: Failure Mode and Effect Analysis of Mobile Water Treatment Device

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
											Actions Taken	New Sev	New Occ	New Det	New RPN
1/2 UPVC female and male adapter	1. Loose fittings. 2. Safety	1. Leaks.	7	Low tightening mechanism. The male and female adapter is not tightened.	9	1. Visual inspections.	2	**126**	Regular inspections.	K. Conde 21/03/2024	Tightening Mechanism. Applied enough teflon tape.	1	3	2	6
First elbow from water pump to filtration.	1. Safety 2. Water wastage 3. Loose fittings.	1. Leaks. 2. Electric shock is present in the overall metal parts of the product due to leaks.	8	1. Improper installation. 2. Lack of solvent cement is applied. 3. Low tightening mechanism.	9	1. Visual inspection.	3	**216**	Regular inspections. Follow installation guidelines.	K. Conde 21/03/2024	Tightening Mechanism. Put enough solvent cement for a robust tightening mechanism.	1	2	2	4
1/2 UPVC Union Patente between filtration and UV Sterilizer.	1. Loose fittings. 2. Water Wastage	1. Leaks 2. Electric shock due to leaks.	7	1. No solvent cement applied. 2. Improper installation.	9	1. Visual inspections. 2. Monitoring the leaks.	3	**189**	Regular inspections. Check if there are leaks.	K. Conde 21/03/2024	Applied enough solvent cement for tightening.	1	1	3	3

Table 8 shows the mobile water treatment device's Failure Mode and Effect Analysis (FMEA). This FMEA addresses specific failure modes and their potential effects, causes, current design method, recommended actions, and actions taken. In addition, the materials listed above have high-value Risk Priority Numbers (RPN). The highest RPN value is in the first elbow from water to filtration, with a value of 216, followed by the 1/2 UPVC Union Patente between filtration and UV Sterilizer, with a value of 189, and the last one with 126. These high RPN values indicate that the materials must be prioritized, monitored, and addressed, and appropriate actions must be taken to reduce the risk and other factors that may affect the use of the mobile water treatment device.

Furthermore, actions were also taken, and the results were a new value of severity (1,1,1), occurrence (3,2,1), detection (2,2,3), and RPN values of 6, 4, and 3. These values indicate that the mobile water treatment device is performing well and reducing the risk, potential impacts, and occurrence of failures decreases as well to ensure that the water treatment components meet or exceed performance expectations. This analysis emphasizes the significance of user feedback and continuous improvement processes to enhance the product's reliability, safety, and longevity.

On the other hand, in terms of component characteristics, the UV sterilizer is considered the most vulnerable component because of its sensitive light tube, which works as a disinfectant. This light tube plays a crucial role in emitting UV radiation, which is pivotal for eradicating pathogens and microorganisms in the water, thereby ensuring the safety of drinking water. However, the fragility of this light tube makes it vulnerable to damage from external factors such as physical impacts or misuse during maintenance. As a result, extra attention must be exercised when handling the UV sterilizer to avoid harming its sensitive components. This preserves the UV sterilizer's integrity and effectiveness in ensuring water safety, reaffirming the device's critical role in supplying clean and potable water.

4. Summary of findings

This section summarizes the significant findings made during this study, summarizing the essential insights and implications of the research study. Through meticulous data analysis and interpretation, the findings presented herein provide valuable insights into various aspects of the study, shedding light on relevant factors influencing the adoption and efficacy of the mobile water treatment device and elucidating critical considerations for its implementation and improvement. The following are the significant findings of the study:

- The study reveals a significant level of acceptance among respondents toward adopting the mobile water treatment device. Ratings across various dimensions of the empathy map demonstrate a strong inclination to embrace the proposed solution, indicating a promising avenue for addressing water-related concerns within the community. Moreover, respondents demonstrate a strong inclination to consider and implement the device in their households. The community exhibits openness to information about the device, indicating potential for word-of-mouth recommendations and awareness of water treatment benefits. The high level of acceptability, which has an average weighted mean of 4.63, underscores the potential effectiveness of the device and emphasizes the importance of clear communication and education campaigns to facilitate its successful integration into household water treatment practices.
- The treated water successfully complies with the criteria outlined in the 2017 Philippine National Standards for Drinking Water, as indicated by passing results in both bacteriological and physical-chemical water tests. Bacteriological tests revealed consistently high levels of total coliform and thermotolerant coliform in untreated well water, indicating contamination. Nevertheless, treated well water showed compliance with standards, demonstrating the effectiveness of the mobile water treatment device. Physical and chemical tests demonstrated that both untreated and treated well water met maximum allowable levels for parameters such as arsenic, cadmium, lead, turbidity, pH, apparent color, total dissolved solids, nitrate, and residual chlorine. These results suggest that the treated water is safe for drinking consumption and is recommendable for usage.
- The mobile water treatment device's water treatment system demonstrates effectiveness in significantly reducing microbial contamination levels. Using mass balance and kinetics models, the study determined the rate of change in microbial contamination within the mobile water treatment system. The laboratory test findings, as assessed using these models, revealed a significant reduction in contaminants. Specifically, after using the combined filtration and UV treatment, the concentration of microbial contaminants dropped from 8 MPN/100mL in the untreated water bacteriological test to roughly 1.107 MPN/100mL in the treated bacteriological test. This significant decrease demonstrates the device's effectiveness in efficiently reducing microbial contamination levels and improving water quality.
- The observation reveals that the water pump is particularly prone to overheating, while the UV sterilizer is recognized as the most vulnerable component due to its sensitive light tube, which serves as a disinfection mechanism. The observation highlights vulnerabilities in the water treatment device. During 3 hours of continuous operation, the water pump's temperature gradually increases, and there are cycles in which the pump’s temperature reaches an overheating temperature. Furthermore, 9 out of 10 observation cycles revealed a leak at the elbow connection between the water pump and the filter. This leakage is caused by the adhesive failing to dry completely during device operation, which could result in electric shock hazards due to the device's metal frame. Additionally, the UV sterilizer has shown sensitivity issues, necessitating two replacements. The first problem was caused by water getting into the UV ballast due to improper placement, causing the pins to burn out and activating a flashing red light, signaling product failure. Therefore, handling the UV sterilizer with extreme caution and observing the proper placement of the UV ballast is essential to avoid inflicting harm on its sensitive components and maintaining its efficiency in ensuring water safety.

5. Conclusion

In conclusion, this study has shed light on a mobile water treatment device's acceptance, efficacy, and operational aspects. The significant findings show that respondents strongly support the device, demonstrating its potential effectiveness in addressing water-related concerns in the community. Furthermore, the treated water demonstrates compliance with the Philippine National Standards for Drinking Water, underscoring the device's effectiveness in enhancing water quality. In addendum, the device's combination of alkaline filter and UV sterilizer demonstrates effectiveness in reducing microbial contamination, deeming its significance in improving water quality. However, the observation highlights system vulnerabilities, particularly the water pump's susceptibility to overheating and the UV sterilizer, which has been identified as the most vulnerable due to its sensitive light tube. These vulnerabilities demand proactive measures and continuous monitoring to reduce risks and assure optimal device operation. Overall, while the mobile water treatment device has the potential to improve water quality and accessibility, regular maintenance and careful handling of critical components are required for its successful implementation and long-term efficacy in water treatment.

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