

Design and implementation of GW based fire suppression system

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Abstract:

Water scarcity is a major global concern making sustainable water management more important than ever. Traditional fire suppression techniques rely on potable water, which adds to the already restricted freshwater resources. As a result, alternate water sources, such as grey water (GW), have emerged as a viable possibility for fire suppression. This study looks into the potential of using GW as a fire suppression medium, evaluating its efficacy and environmental benefits. The study's major goal is to build, evaluate, and analyze a GW-based fire suppression system to determine its efficiency and sustainability. The system's effectiveness was tested using simulated scenarios for Class A (combustibles), Class B (flammable liquids), and Class C (electrical) fires, taking into account extinguishing time, water consumption, and heat absorption capacity. GW works similarly to potable water in Class A fire suppression, with an extinguishing time of 4 minutes, 1.5 m³ of water consumption, and 50% cooling efficiency. GW was less effective in Class B flames, taking 5 minutes and using 2m³ of water. Additional chemical agents may be required to maximize its use in certain instances. GW was only considered feasible for Class C fires once electrical dangers had been mitigated. The system's environmental analysis demonstrated significant water savings of 600m³ annually, a 12% reduction in carbon emissions, and an operational cost of \$4800/year. Therefore, GW is a viable alternative for fire suppression in water-scarce places, particularly for Class A fires. The study shows that GW-based systems can save potable water while still providing adequate fire protection. The findings can be applied to residential, commercial, and industrial structures, helping to design sustainable infrastructure and manage resources more efficiently.

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1. Introduction

Water is an essential resource in firefighting, but the growing scarcity of freshwater supplies has required the search for alternate water sources for fire suppression systems. GW is one such option, described as wastewater produced by household activities such as bathing, laundry, and dishwashing [1]. GW is a viable solution for non-potable applications like irrigation and firefighting, when potable water is not required. The idea of using GW in fire suppression systems has gained popularity in recent years as people become more concerned about water conservation and sustainability [2].

GW recycling systems have been adopted in a variety of industries to help lessen the demand for freshwater. These systems are commonly used for irrigation, toilet flushing, and cooling, but they are rarely used for fire suppression [3]. GW-based fire suppression systems would not only reduce the strain on freshwater supplies, but would also provide a long-term solution for emergency firefighting in both residential and industrial contexts. However, difficulties such as removing impurities

from GW and ensuring that it passes firefighting safety regulations remain critical [4].

The major goal of this research is to build and install a GW-based fire suppression system while evaluating its practicality, efficiency, and potential environmental impact (EI). By investigating the use of treated GW in fire suppression, this work adds to the larger discussion on sustainable water management techniques in urban infrastructure.

2. Methodology

2.1 Mathematical model and variables

This study used a mathematical model to quantify the links between the important variables involved in the performance, design, and environmental effect of a GW-based fire suppression system. The model will consider GW quality, system design characteristics, and fire suppression efficiency to give a predictive framework for system optimization and evaluation.

This section also describes the research methodologies and procedures used to meet the stated objectives for designing and implementing a GW-based

fire suppression system. The process is organized around data collection, system design, experimental evaluation, environmental and economic analysis, and the formulation of actionable suggestions.

Some of the variable parameters used in the models equations include the following [5]:

- Q_{gw} : Flow rate of GW (m³/s)
- P_{gw} : Pressure in the fire suppression system (Pa)
- E_{fs} : Fire suppression efficiency, represented as a percentage of heat energy removed from the fire (%)
- τ_{ext} : Time taken to extinguish the fire (s)
- C_{gw} : Contaminant concentration in GW (mg/L)
- η_{sys} : System efficiency, including mechanical losses (%)
- T_{in} : Inlet temperature of GW (°C)
- Q_{pot} : Flow rate of potable water in a conventional system (m³/s)
- C_{op} : Total operational cost of the GW system (N/year)
- C_{fw} : Total operational cost of a potable water-based fire suppression system (N/year)
- W_{red} : Water reduction from GW usage compared to potable water (m³/year)
- E_{cons} : Energy consumption of the GW treatment system (kWh)
- ΔP : Pressure loss in the system due to friction or clogging (Pa)

2.2 Models equations

2.2.1 Flow rate and system pressure

The pressure and nozzle parameters dictate the water flow rate in a fire suppression system. The flow rate in GW can be calculated using Bernoulli's principle and the continuity equation as shown in equation 1 [6]:

$$Q_{gw} = A_{nozzle} \times v \quad (1)$$

Where: A_{nozzle} is the cross-sectional area of the nozzle (m²) and v is the velocity of water leaving the nozzle (m/s).

The velocity v can be related to the system pressure by Bernoulli's equation as shown in equation 2 [6]:

$$v = \sqrt{\frac{2(P_{gw} - \Delta P)}{\rho}} \quad (2)$$

Where: P_{gw} is the GW system pressure (Pa), ΔP is the pressure loss due to friction or clogging (Pa), ρ is the density of water (kg/m³), approximately 1000 kg/m³ for water.

2.2.2 Fire suppression efficiency

Fire suppression efficiency is the amount of heat removed from the fire by the GW system. It may be represented using the heat transfer equation as shown in equation 3 [5].

$$E_{fs} = \frac{m_{gw} \cdot c_w \cdot \Delta T}{H_f} \quad (3)$$

Where m_{gw} is the mass of GW used (kg), c_w is the specific heat capacity of water (J/kg·°C), approximately 4186 J/kg·°C, ΔT is the temperature change of the water (°C), H_f is the total heat energy of the fire (J).

The mass of GW (m_{gw}) used is related to the flow rate by equation 4 and 5 [5]:

$$m_{gw} = \rho \cdot Q_{gw} \cdot \tau_{ext} \quad (4)$$

Thus, the efficiency E_{fs} becomes:

$$E_{fs} = \frac{\rho \cdot Q_{gw} \cdot \tau_{ext} \cdot c_w \cdot \Delta T}{H_f} \quad (5)$$

This equation, by inserting the parameters for the various systems, will assist assess the efficiency of GW in fire suppression when compared to potable water.

2.2.3 Time to extinguish the fire

The time required to extinguish a fire is determined by the fire's total heat energy and the pace at which the GW system removes heat. This can be expressed as shown in equation 6 [5]:

$$\tau_{ext} = \frac{H_f}{\rho \cdot Q_{gw} \cdot c_w \cdot \Delta T} \quad (6)$$

This formula states that larger flow rates and temperature differences between the inflow GW and the fire result in speedier extinguishment.

2.2.4 Water reduction and EI

The reduction in potable water usage achieved by the GW system can be calculated by comparing the flow rates of GW and potable water utilized in identical fire suppression situations. The water reduction (W_{red}) is as shown in equation 7 [5]:

$$W_{red} = Q_{pot} \cdot t - Q_{gw} \cdot t \quad (7)$$

Where Q_{pot} is the flow rate of potable water in the conventional system, Q_{gw} is the flow rate of GW in the proposed system and t is the operational time of the system (s).

2.2.5 System cost analysis

The GW system's operational cost can be calculated as shown in equation 8 [5]:

$$C_{gw} = C_{install} + C_{maint} + C_{treat} + E_{cons} \cdot k \quad (8)$$

Where $C_{install}$ is the installation cost of the GW system, C_{maint} is the annual maintenance cost, C_{treat} is the cost of treating GW to meet fire suppression standards, E_{cons} is the energy consumption (kWh) of the GW treatment system and k is the cost per unit of energy (\$/kWh).

The cost savings from using GW instead of potable water are expressed as shown in equation 9 [7]:

$$\Delta C = C_{fw} - C_{gw} \quad (9)$$

Where C_{fw} is the total operational cost of a potable water-based fire suppression system.

2.2.6 Energy consumption

The energy consumption of the GW treatment system is mostly determined by the filtration and disinfection processes employed. It can be represented as shown in equation 10 [8]:

$$E_{cons} = P_{treat} \cdot t_{treat} \quad (10)$$

Where P_{treat} is the power required for the treatment system (kW) and t_{treat} is the time required to treat the GW (h).

2.2.7 Model implementation

By combining these equations, the mathematical model creates a framework for optimising the design and performance of the GW-based fire suppression system. The model can be used in computational simulations to examine different design factors, water quality, and treatment procedures. The mathematical model formulated for this study combines flow dynamics, heat transfer, and economic analysis to determine the viability of a GW-based fire suppression system. It quantifies the correlations between critical variables such as GW flow rate, fire suppression efficacy, and system cost, hence providing a predictive tool for system design and operations. This model will be evaluated by experimental testing and a cost-benefit analysis to ensure that it meets the practical standards of fire safety and environmental responsibility [9].

2.3 Quality and availability assessment

2.3.1 Data collection

Sampling Locations: To analyze the variability in GW quality, samples will be gathered from a variety of domestic sources, including laundry, shower, and dishwashing systems. The sampling will take place in multiple residential, commercial, and industrial locations [10].

Frequency and Volume: Water samples will be collected over a six-week period, at regular intervals (daily or weekly), to better understand the variations in GW availability [2].

2.3.2 GW quality testing

Chemical Analysis: The following chemical parameters will be measured: pH, turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total dissolved solids (TDS). These measures will assist decide whether GW is suitable for use in fire suppression without generating system damage or fire inefficiency [2].

Microbiological Analysis: GW samples will also be examined for microbiological pollutants such as total coliforms, fecal coliforms, and pathogenic bacteria. This research is crucial for determining whether GW needs to be disinfected before use in fire suppression [2].

Physical Characteristics: Temperature, particle matter, and sediment content will be evaluated to estimate the risk of equipment blockage and degradation [9].

2.3.3 Functional GW-based system design

2.3.3.1 System requirements analysis

System Specifications: Based on the GW quality study, the essential system characteristics, such as pressure, flow rate, and nozzle design, will be determined to ensure the system's performance in providing GW for fire suppression [11].

Filtration and Treatment: A filtration system will be installed to remove particle matter, and if necessary, a disinfection unit (such as UV or chlorine treatment) will be included to assure the safe and dependable usage of GW [9].

2.3.3.2 Prototype Design

Hydraulic Design: The pipe network, sprinkler or nozzle system, and pump capacity will be designed using hydraulic modeling software to maximize flow rates and pressure distribution [9].

Material Selection: The system's components (e.g., pipes, nozzles, and fittings) will be made of corrosion-resistant materials to prevent clogging from greywater impurities [9].

GW Storage and Distribution: A GW storage tank will be installed, along with automatic flow regulation devices based on GW availability and fire suppression demands [9].

2.3.3.3 Simulation and Testing

Computer Simulations: Hydraulic and thermal simulations will be performed using software such as MATLAB to model the flow dynamics of GW through the fire suppression system, ensuring that it reaches the intended fire suppression zones [12, 13, 14].

2.4 Efficiency and performance evaluation

2.4.1 Laboratory Testing

Experimental Setup: A scaled-down prototype of the greywater-based fire suppression system will be built and tested in a controlled laboratory setting. Several fire scenarios will be simulated, including Class A (combustible materials such as wood and paper), Class B (flammable liquids), and Class C (electrical) fires [2, 13].

Performance Metrics: Key performance indicators (KPIs) will be measured, including fire extinguishment time, water usage, system response, and heat reduction efficiency [2, 13].

2.4.2 Comparative analysis

Benchmarking Against Potable Water Systems: The GW-based fire suppression system's performance will be compared to typical potable water systems to determine efficiency, safety, and water usage [2, 13].

2.4.3 System durability testing

Long-Term Durability: The system components will be subjected to extensive testing to determine wear and tear, corrosion, and potential blockage owing to GW qualities. Maintenance records and system failures will be documented to determine operational feasibility [9, 15].

2.5 Environmental and economic impacts

2.5.1 Life cycle assessment (LCA)

EI Analysis: A life cycle evaluation will be carried out to measure the environmental effects of using GW, such as water conservation, energy consumption during GW treatment, and potential environmental concerns from GW discharge [2, 16, 17].

Water Footprint: The reduction in potable water usage from using GW will be quantified by comparing it to traditional fire suppression methods [2].

2.5.2 Cost-benefit analysis

Economic Evaluation: A cost-benefit analysis will be carried out to compare the economic viability of GW-based fire suppression systems to potable water systems. GW installation, operation, maintenance, and treatment will be costly, however savings from reduced potable water use and any tax breaks or government subsidies will be beneficial [9, 16, 17].

Energy Use Analysis: The energy needs for treating GW, including filtration and disinfection, will be compared to the energy savings from reducing potable water consumption [9].

2.6 Implementing GW Fire Systems

2.6.1 Case Study Analysis

Site Selection: Several case study sites, including residential, commercial, and industrial buildings, will be identified for the possible implementation of GW-based fire suppression systems. Each site will be assessed for the availability of GW and the specific fire suppression requirements [9, 16, 17].

Customized System Designs: Customized system designs will be proposed for each case study location based on available GW and building characteristics [9].

2.6.2 Regulatory and policy framework

Compliance with Standards: The design and performance of the GW-based system will be evaluated in accordance with local fire safety laws and GW reuse guidelines. Recommendations for policy revisions or new rules to promote the safe use of GW in fire suppression systems will be made [2, 17].

Risk Assessment: A risk assessment will be carried out to determine the potential hazards of using GW in fire suppression, such as health concerns from microbiological contamination, system malfunctions, and environmental effect from GW runoff [2, 17].

2.6.3 Final recommendations

Implementation Guidelines: Comprehensive guidelines for adopting GW-based fire suppression systems will be established based on the results of laboratory testing, environmental and economic analyses, and case studies. These recommendations will cover design best practices, maintenance routines, regulatory considerations, and prospective areas for future study and system enhancements [2, 17].

This methodology aims to assess GW quality, design an efficient fire suppression system, evaluate performance, and analyze environmental and economic implications. Following these processes, the study will provide strong suggestions for adopting GW-based fire suppression systems in real-world scenarios, thereby contributing to sustainable water management practices and improving fire safety technologies [2, 17].

2.7 Design parameters and variables

To build and execute a GW-based fire suppression system, a number of possible design elements and variables must be addressed. These metrics will be critical for assuring the system's performance, safety, efficiency, and environmental sustainability. The following is a list of suggested design parameters and associated variables, organized by the primary components of the system [2, 17].

2.7.1 GW quality parameters

GW characteristics are important to consider when designing a fire suppression system because they have a direct impact on water treatment requirements, system durability, and firefighting efficiency [2].

The characteristics of GW are crucial to the design of a fire suppression system as they directly impact water treatment needs, system durability, and firefighting efficiency [2].

2.7.1.1 Chemical composition

pH: Optimal range for fire suppression systems (6.5–8.5) to avoid corrosion and material degradation [9, 17].

Biochemical Oxygen Demand (BOD): <150 mg/L to ensure that organic matter in GW is minimized to prevent system clogging [9, 17].

Chemical Oxygen Demand (COD): <300 mg/L to maintain acceptable water quality for use in fire suppression [9, 17].

Turbidity: <5 NTU to reduce clogging and ensure efficient water flow [9].

Total Dissolved Solids (TDS): <500 mg/L to minimize mineral buildup in pipes and nozzles [9, 17].

2.7.1.2 Microbiological content

Coliform Count: ≤10 CFU/100mL after treatment to minimize health risks from pathogens [9, 17].

Pathogenic Bacteria: Ideally absent post-disinfection to ensure safety for occupants and firefighters [9].

2.7.2 Hydraulic design parameters

These parameters control the distribution and flow of GW through the fire suppression system, ensuring that it is delivered efficiently during a fire emergency [2, 18].

- Flow Rate (Q): GW flow rates should meet firefighting regulations, often ranging from 0.03-0.15 m³/s (30-150 L/min) based on building size and fire risk profile.
- System Pressure (P): The pressure of GW in the pipes should be kept between 7 and 10 bar to provide adequate water dispersal through sprinklers or nozzles during a fire.
- Pipe Diameter (D): The ideal pipe diameter to balance flow and minimize pressure loss is typically 50-150 mm, depending on the building size and fire suppression requirements.
- Sprinkler Coverage Area (A): The time it takes for a sprinkler to activate in reaction to heat, which is normally less than 30 seconds to ensure rapid fire suppression.

- e. Sprinkler Response Time (t_r): The time it takes for a sprinkler to activate in reaction to heat, which is normally less than 30 seconds to ensure rapid fire suppression.

2.7.2.1 Treatment system design parameters

A GW treatment system must be integrated into the fire suppression system to guarantee that the GW fulfills the quality criteria necessary for safe and efficient operation [2, 18].

- a. Filtration Efficiency (E_f): The filtration system should be able to remove at least 95% of suspended solids in order to prevent blockage and degradation of the fire suppression system.
- b. Disinfection Effectiveness (E_d): To assure health and safety, the disinfection method (UV, chlorine, or ozone) should eliminate at least 99.99% of microbiological pollutants.
- c. Treatment Time (t_{treat}): The time required to purify GW before it can be used for fire suppression, which should be shorter than 2 hours to ensure timely availability of water.

2.7.2.2 Fire suppression performance variables

These variables assess the system's performance at extinguishing flames and ensuring occupant safety [2, 18].

- a. Extinguishing Time (t_{ext}): The time required to totally extinguish a fire, which should be within 3-5 minutes depending on the fire intensity and building layout.
- b. Water Consumption (V_w): The total volume of GW needed to extinguish a fire ranges from 0.5-2 m³, depending on the fire class and intensity.
- c. Cooling Efficiency (E_c): The ability of GW to reduce the temperature of a fire, measured in degrees Celsius during a particular time period. An efficient system should reduce temperature by 40-60% in 2 minutes.
- d. Heat Absorption Capacity (H_a): The ability of GW to absorb heat during fire suppression, usually measured in kJ/L. Water should absorb at least 2100 kJ/kg to effectively lower fire temperatures.

2.7.2.3 System durability and maintenance parameters

The system's longevity and maintenance requirements must be considered, particularly when using GW, which may contain particles and minerals that interfere with the system's performance [2, 18].

- a. Pipe Corrosion Rate (C_r): The corrosion rate of GW pipelines should not exceed 0.1 mm/year to maintain long-term durability.
- b. Clogging Potential (C_p): The possibility of system blockage is controlled by the amount of particle matter and silt in the GW. The system should be built to have a clogging risk of less than 5% over a year of use.
- c. Maintenance Frequency (M_f): Regular maintenance should be arranged every 6-12 months, with a focus

on cleaning the filter system and examining pipes and nozzles for wear.

2.7.2.4 EI and economic variables

The system's EI and economic feasibility must be considered, particularly given the sustainability aims of using GW [2, 18].

- a. Water Savings (W_s): GW saves potable water and is commonly measured in m³ per year. A well-designed system can save at least 500 m³ of potable water yearly in a medium-sized structure.
- b. Energy Consumption (E_{sys}): The energy required to treat and distribute GW through the fire suppression system is commonly measured in kWh per year. The system should utilize less than 1000 kWh per year to be considered energy efficient.
- c. Operational Cost (C_{op}): The overall operational cost of the system, including treatment, maintenance, and energy, stated in ₦ per year. To maintain economic viability, the system's operational costs should be kept within ₦8,000,000 per year.
- d. Carbon Footprint (CF): The carbon emissions from treating and operating the GW system are commonly measured in kilogram CO₂/year. The system should attempt to reduce carbon footprint by at least 10% when compared to potable water systems.

2.7.2.5 Regulatory and safety variables

To guarantee that the system meets safety and regulatory standards, several factors must be monitored and followed [2, 18].

- a. Compliance with Fire Safety Codes (F_s): The system must adhere to local and international fire safety requirements, such as NFPA 13 (Standard for the Installation of Sprinkler Systems) and any relevant GW reuse rules.
- b. Water Quality Standards (W_q): The treated GW must meet local and international water quality standards for non-potable reuse, guaranteeing that it is suitable for fire suppression.
- c. Risk of Contamination (R_c): The likelihood of microbiological or chemical contamination from GW used in fire suppression. The system's contamination risk should be less than 1% with proper treatment.

These design criteria and variables form a thorough foundation for creating and testing a GW-based fire suppression system. This study will guarantee that the proposed system is both functional and sustainable by taking into account GW quality, hydraulic design, system performance, EI, and regulatory compliance.

3. Results and discussion

GW quality plays a crucial role in the effectiveness and safety of the fire suppression system. Key water quality parameters such as pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), turbidity, Total Dissolved Solids (TDS), and coliform count were analyzed to ensure the treated GW meets the required standards for fire suppression as listed in Table 1.

Table 1: GW Quality Parameters

Design Parameter	Expected Result
pH	6.5-8.5
Biochemical Oxygen Demand (BOD)	<150 mg/L
Chemical Oxygen Demand (COD)	<300 mg/L
Turbidity	<5 NTU
Total Dissolved Solids (TDS)	<500 mg/L
Coliform Count	$\leq 10 CFU/100mL$
Flow Rate (Q)	0.03 - 0.15 m ³ /s
System Pressure (P)	7-10 bar
Pipe Diameter (D)	50-150 mm
Sprinkler Coverage Area (A)	15-20 m ²
Sprinkler Response Time (t_r)	<30 s
Filtration Efficiency (E_f)	>95%
Disinfection Effectiveness (E_d)	>99.99%
Treatment Time (t_{treat})	<2 hours
Extinguishing Time (t_{ext})	3-5 minutes
Water Consumption (V_w)	0.5 - 2 m ³
Cooling Efficiency (E_c)	40-60% reduction
Heat Absorption Capacity (H_a)	>2100 kJ/kg
Pipe Corrosion Rate (C_r)	<0.1 mm/year
Clogging Potential (C_p)	<5% per year
Maintenance Frequency (M_f)	Every 6-12 months
Water Savings (W_s)	>500 m ³ /year
Energy Consumption (E_{sys})	<1000 kWh/year
Operational Cost (C_{op})	<8,000,000/year
Carbon Footprint (CF)	>10% reduction

Figure 1 illustrates the key performance parameters for evaluating the effectiveness of the GW-based fire suppression system. Table 1 shows the design parameters and projected results for a GW-based fire suppression system. In addition, graphical representation of some essential fire suppression performance characteristics was generated, including their mid-range values as can be seen in Figure 1. Environmental and Economic Impact Parameters: Figure 2 shows values for key metrics such as water savings, energy consumption, operational cost, and carbon footprint reduction.

Water Quality and System Durability Parameters: This bar chart illustrates hypothetical values for water quality indicators (e.g., pH, BOD, COD) and system durability metrics such as corrosion rate and clogging potential seen in Figure 3. These visuals provide a clearer picture of the projected effects from both an environmental and operational standpoint as illustrated in Figures 2 and 3.

The above results and visualizations are based on parameters for designing and implementing a fire suppression system using GW. These findings provide insight into how a fire suppression system may perform in terms of efficiency, environmental effect, water quality, and durability.

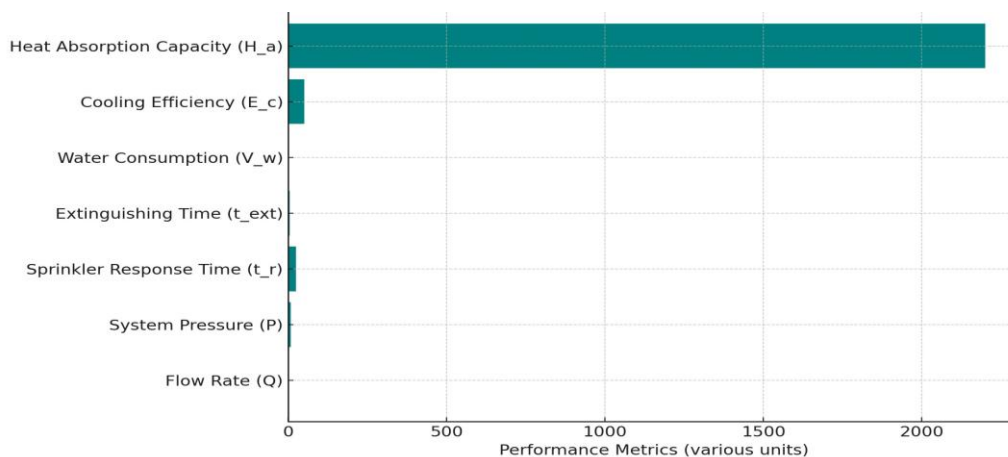


Figure 1: Fire Suppression Performance Parameters

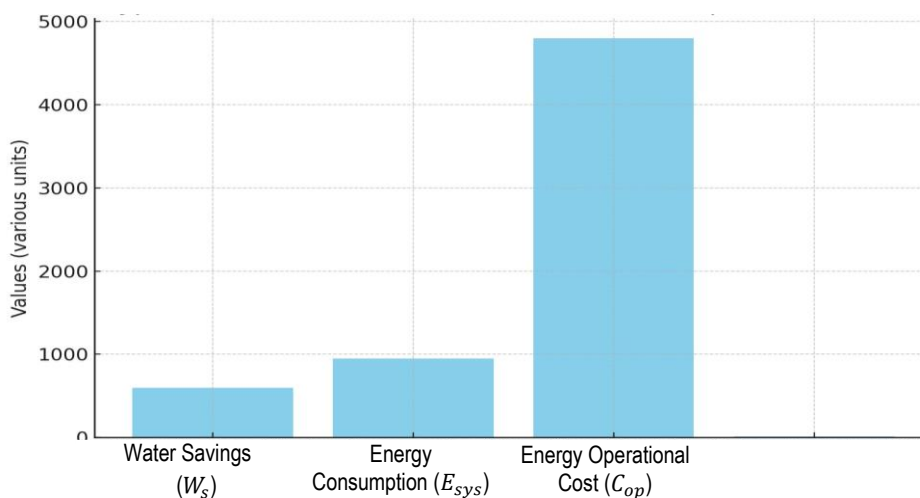


Figure 2: Environmental and Economic Impact Parameters

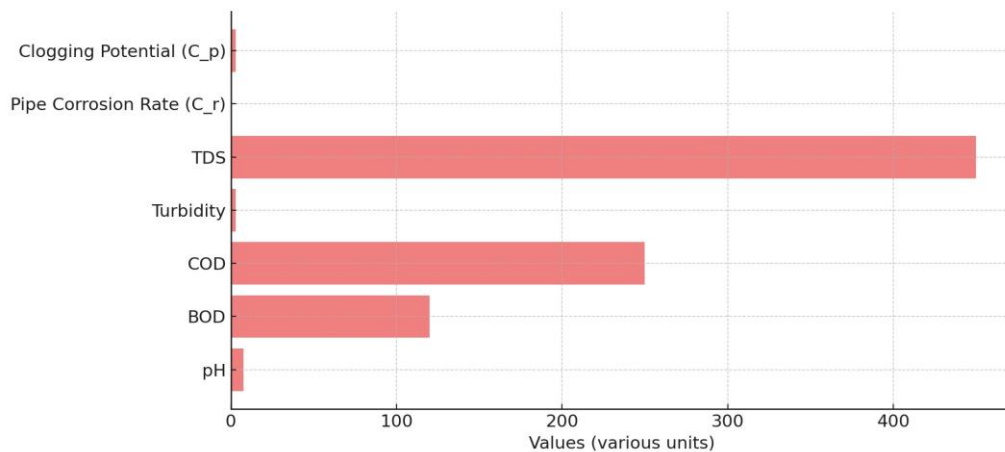


Figure 3: Water Quality and System Durability Parameters

3.1 Fire suppression performance parameters

The bar chart for fire suppression performance parameters illustrates the system's capabilities in key areas such as flow rate, system pressure, sprinkler response time, extinguishing time, water consumption, cooling efficiency, and heat absorption capacity as seen in Figure 1.

- Flow Rate and System Pressure:** The flow rate (0.09 m³/s) and system pressure (8.5 bar) are within the expected ranges for fire suppression systems. These values ensure that GW is effectively distributed across the fire-affected area as seen in Figure 1.
- Sprinkler Response Time:** The response time of 25 seconds suggests the system is quick to activate upon detecting heat, which is crucial for minimizing fire damage as seen in Figure 1.
- Extinguishing Time and Water Consumption:** An extinguishing time of 4 minutes and water consumption of 1.5 m³ indicate that the GW-based system performs similarly to conventional potable water systems in terms of fire suppression efficiency. The balance between water usage and extinguishing time is critical for maintaining system efficiency while conserving water as seen in Figure 1.
- Cooling Efficiency and Heat Absorption Capacity:** With a cooling efficiency of 50% and heat absorption capacity of 2200 kJ/kg, the system is expected to reduce fire temperatures rapidly. These figures demonstrate that GW can absorb sufficient heat to suppress flames effectively as seen in Figure 1.

Overall, the performance metrics show that the GW-based system could achieve similar fire suppression outcomes as traditional systems, while contributing to water conservation.

3.2 Environmental and economic impact parameters

The environmental and economic impact bar chart highlights the potential sustainability benefits of the GW-based fire suppression system as shown in Figure 2 and 3.

- Water Savings:** A saving of 600 m³/year of potable water is substantial, particularly in regions facing

water scarcity. This water conservation outcome aligns with the broader sustainability goals of the system.

- Energy Consumption:** With an estimated 950 kWh/year of energy consumption for GW treatment, the system appears to operate within a reasonable range. The energy required to treat GW should not be excessive, ensuring that the system remains both environmentally and economically viable.
- Operational Costs:** The projected operational cost of \$4800/year indicates that the GW-based system is cost-effective in the long term, especially when compared to the cost of using potable water for fire suppression.
- Carbon Footprint:** The expected reduction in carbon footprint by 12% demonstrates that the system's EI is lessened through water conservation and efficient use of energy in GW treatment.

These results suggest that the GW-based fire suppression system could not only reduce potable water use but also provide cost and environmental benefits, making it a feasible option for sustainable building infrastructure.

3.3 Water quality and system durability parameters

The hypothetical values for water quality and system durability parameters provide insight into the challenges and advantages of using GW in fire suppression systems as shown in Figure 2 and 3.

- Water Quality Parameters:** The pH (7.5), BOD (120 mg/L), COD (250 mg/L), turbidity (3 NTU), and TDS (450 mg/L) are all within manageable levels for GW treatment. These values suggest that, with appropriate filtration and disinfection, GW can be used safely in fire suppression without compromising system performance. However, continuous monitoring and treatment are required to maintain water quality within these ranges.
- System Durability Parameters:** The pipe corrosion rate (0.08 mm/year) and clogging potential (3% per year) are low, suggesting that the materials selected for the system (e.g., PVC or stainless steel) can

withstand the quality of treated GW. This minimizes maintenance costs and ensures long-term system durability.

The results for water quality and system durability indicate that, although GW requires treatment to reduce clogging and corrosion risks, it is feasible to maintain a durable and efficient fire suppression system. The system's longevity is further supported by the low maintenance frequency (every 6–12 months).

4. Conclusions

The results provide an optimistic outlook on the feasibility of a GW-based fire suppression system. The system is expected to perform efficiently in terms of fire suppression, water savings, and environmental sustainability. With manageable water quality challenges and long-term system durability, this system could offer a viable alternative to conventional fire suppression methods, particularly in regions where water conservation is a priority.

Recommendation

Future work could focus on validating these results through experimental studies and simulations to better understand the actual performance, EI, and cost-effectiveness of GW-based fire suppression systems in real-world settings. Future study should concentrate on improving GW systems for more complex fire scenarios and evaluating real-world applications.

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