

Effectiveness of Gradual Filtration Technology for Drinking Water Quality and Student Competence in Jayapura, Indonesia

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ABSTRACT: Access to safe, high-quality drinking water remains an unmet basic need in many religious educational institutions, particularly Islamic boarding schools in Papua. This study evaluated pretest–posttest changes associated with an appropriate-technology multi-stage filtration system designed to improve drinking water quality and students’ water-management competencies at Papua Madani Boarding School (PMBS), Jayapura City. Using a pre-experimental one-group pretest–posttest design, the study involved 45 students, of whom 20 senior students were selected as the primary intervention group. The intervention included six training modules and the construction of a filtration system with a capacity of 1,000 L/day. Data were collected through laboratory analyses of water-quality parameters and assessments of student competencies. The results were analyzed descriptively because the available data did not support inferential statistical testing. Total dissolved solids (TDS) decreased from 559 mg/L to 88 mg/L, color decreased from 11 to 6 NTU, and total coliform decreased from >100 CFU/100 mL to 0 CFU/100 mL. Student competency scores increased from 18% to approximately 85%. These findings indicate that integrating appropriate filtration technology with capacity-building activities has the potential to support sustainable drinking water management in Islamic boarding schools.

KEYWORDS: Effectiveness; water filtration; drinking water quality; student competence; tahfidz islamic boarding school

1. Introduction

Access to safe, high-quality, and affordable drinking water is a fundamental human right, yet adequate water supply remains a challenge in many religious educational institutions in Indonesia, including Islamic boarding schools. Dense communal living conditions, combined with inadequate sanitation and limited access to safe water, can increase students’ exposure to water- and sanitation-related diseases [1]. Inadequate sanitation facilities in these institutions

have also been associated with a high prevalence of environmentally related illnesses [2, 3]. Approximately 67% of Islamic boarding schools in Indonesia reportedly continue to experience limitations in adequate sanitation and clean-water facilities [4]. At the national level, progress toward Sustainable Development Goal (SDG) indicator 6.1.1 on safely managed drinking water remains constrained by regional disparities in water quality and microbiological contamination of household water systems [5]. These challenges highlight the need for affordable and locally manageable water-treatment technologies, particularly in educational institutions located in areas with limited infrastructure.

Papua Madani Boarding School (PMBS), a Tahfidz Islamic boarding school in West Koya, Jayapura City, represents one such setting. Established in 2019, PMBS implements an intensive *tahfidz* program targeting the memorization of 30 *juz* within three years. The school accommodates 45 students, comprising 27 males and 18 females aged 13–23 years. The boarding school relies primarily on groundwater for its daily water supply. However, the quality of the well water fluctuates considerably, with turbidity reportedly reaching 15–25 NTU during the rainy season. Consequently, the school purchases refill drinking water at an estimated cost of IDR 1,000,000–1,500,000 per month to meet a daily drinking water demand of approximately 70–90 L. These conditions create both technical and financial challenges for maintaining a reliable drinking water supply.

The challenge is not limited to water quality and infrastructure but also involves the capacity of users to operate and maintain water-treatment systems. Preliminary focus group discussions conducted in November 2025 indicated that only 18% of the students understood the basic principles of water filtration and disinfection. Limited technical knowledge, combined with the absence of an on-site drinking water treatment system, resulted in substantial dependence on externally supplied drinking water. Therefore, a sustainable intervention requires not only an effective treatment technology but also the development of local competencies for its operation, monitoring, and maintenance. Appropriate-technology-based filtration has been increasingly applied as a decentralized approach to improving water supply in communities with limited treatment infrastructure. The installation of filtration systems in Islamic boarding schools has been reported as a practical approach to addressing clean-water limitations and provides a model that can potentially be adapted to similar institutional settings [6]. Water-source assessment, educational activities, and feasibility evaluation are also important before implementing permanent treatment technologies [7, 8]. Furthermore, participatory approaches to developing water facilities can strengthen environmental awareness and user involvement in system management [9]. Appropriate technologies can also be combined with locally suitable energy solutions, such as solar-powered water pumps, to address infrastructure limitations in areas with unreliable conventional services [10].

Previous studies have demonstrated the technical potential of multi-stage filtration for improving water quality. In the Sentani District, a multi-stage filtration system effectively reduced turbidity and microbiological contamination in local water sources [11]. Similarly, the integration of mechanical filtration, activated carbon adsorption, and disinfection improved water quality in Yamta Village [12]. Combined aeration and multi-stage filtration have also been applied to reduce iron and manganese concentrations in groundwater [13]. Beyond technical performance, however, the sustainability of community-based drinking water systems depends strongly on user participation, local ownership, and the capacity to operate and maintain the introduced technology [14].

Despite these developments, an important research gap remains. Previous studies have predominantly examined the technical performance of filtration technologies in reducing physical, chemical, or microbiological contaminants, while comparatively limited attention has been given to the human capacity required to sustain their operation. In institutional settings such as Islamic boarding schools, technological effectiveness alone may not ensure long-term functionality if users lack the knowledge and practical competencies required for routine operation, monitoring, and maintenance. An integrated assessment that considers both water-quality improvement and user competency is therefore necessary to better understand the practical sustainability of decentralized drinking water treatment.

To address this gap, the present study integrates an appropriate-technology multi-stage filtration system with structured student capacity building at PMBS in Jayapura, Indonesia. The novelty of the study lies in evaluating the intervention through two complementary dimensions: changes in drinking water quality and changes in students' water-management competencies. Rather than treating students solely as beneficiaries of the technology, the approach positions them as active participants in the operation and maintenance of the drinking water treatment system. This integration provides a basis for developing a student-managed water-treatment model that may be applicable to other boarding schools and educational institutions facing similar water-supply constraints.

Accordingly, this study aimed to evaluate changes in drinking water quality and student competencies following the implementation of an appropriate-technology multi-stage filtration system combined with structured training at PMBS. Specifically, the study assessed changes in selected water-quality parameters before and after filtration, evaluated changes in students' competencies before and after training, and examined institutional considerations relevant to the sustainability of student-based drinking water management. The study contributes to SDG 6 (Clean Water and Sanitation) by addressing access to safer drinking water, while its capacity-building component is relevant to SDG 4 (Quality Education) and SDG 3 (Good Health and Well-being).

2. Materials and Methods

2.1 Types and Design of Research.

This study employed a pre-experimental, one-group pretest–posttest design integrating quantitative assessment with qualitative supporting data. The intervention was implemented in a single institutional setting, Papua Madani Tahfidz Boarding School (PMBS), and involved two components: installation of an appropriate-technology multi-stage drinking water filtration system and implementation of a structured student training program. Measurements were conducted before the intervention (pretest) and after its implementation (posttest) for two principal outcomes: drinking water quality and student competency. This design enabled the study to characterize changes in both outcomes within the same institutional setting. Because no control or comparison group was included, observed pretest–posttest changes were interpreted as changes associated with the intervention rather than as definitive causal effects. Qualitative observations were additionally used to describe institutional implementation and the sustainability of the student-based drinking water management model.

2.2. Study Location and Period.

The study was conducted at PMBS in West Koya, Jayapura City, Indonesia, approximately 15 km from the Jayapura University of Science and Technology (USTJ) campus. Baseline assessment and preliminary data collection began in November 2025. The filtration intervention, training, field mentoring, and follow-up activities were subsequently conducted over an eight-month implementation period extending into 2026.

2.3. Study Population and Participants.

The study population comprised all 45 active PMBS students, including 27 male and 18 female students aged 13–23 years. Participants were selected purposively according to their level of involvement in the intervention. Twenty senior students constituted the primary intervention group and participated in the complete training program, filtration-system assembly, operation, monitoring, and maintenance. The remaining 25 junior students formed a secondary group that received knowledge transfer and participated in broader educational activities. Boarding school caretakers and administrators were also involved as supporting participants, particularly in institutional development, operational supervision, and sustainability planning. This participant structure was intended to combine technical capacity building among senior students with broader dissemination of water and sanitation knowledge within the boarding school community.

2.4. Intervention and Study Variables.

The principal intervention consisted of an appropriate-technology multi-stage filtration system with an installed treatment capacity of 1,000 L/day. The treatment train comprised two major stages. The first stage was designed for clean-water production and incorporated 3- and 1- μm polypropylene (PP) filters, cation-exchange resin, a carbon block cartridge (CTO), and granular activated carbon (GAC). The second stage was designed for drinking-water production and incorporated silica filtration, activated carbon, a 1- μm PP filter, and ultraviolet (UV) disinfection. The system was configured as a sequential treatment process integrating physical filtration, ion exchange, adsorption, and UV disinfection. These treatment mechanisms were intended to improve the physical, chemical, and microbiological characteristics of the source water before consumption. Two principal outcome variables were evaluated. Drinking water quality was assessed using 14 physical, chemical, and microbiological parameters: temperature, total dissolved solids (TDS), turbidity, color, odor, pH, nitrate, nitrite, iron, manganese, residual chlorine, fluoride, *Escherichia coli*, and total coliform. Student competency was assessed based on knowledge and practical competencies related to basic water-treatment principles, filtration-system operation, routine maintenance, water-quality monitoring, and drinking water management.

2.5. Data Collection and Intervention Procedures.

Water-quality data were obtained through laboratory analyses of source water and treated water samples in collaboration with the Jayapura City Health Office. Baseline samples were collected before the filtration system became operational, whereas post-intervention samples were collected after the treatment system was fully operational. The measured parameters were subsequently compared with the applicable drinking water quality standards established by the

Indonesian Ministry of Health. Student competency was evaluated before and after a six-module training intervention comprising 24 effective training hours. The modules covered the fundamentals of clean water and health, principles of water-treatment technology, hands-on construction and assembly of the filtration system, system operation and maintenance, water-quality monitoring, and organizational and financial management. The program employed a learning-by-doing approach to integrate theoretical understanding with direct practical experience.

The same competency domains were assessed before and after training to ensure consistency in evaluating changes associated with the intervention. The assessment covered fundamental water-treatment principles, filtration-system operation, maintenance procedures, and water-quality management. Competency achievement was expressed as an aggregate percentage score representing the overall level of knowledge and mastery across the assessed domains. Accordingly, the baseline score of 18% and post-training score of approximately 85% represent aggregate competency scores rather than the percentages of students classified as competent. Post-training certification was based on students' demonstrated understanding and practical ability to operate and maintain the filtration system and manage water quality. Institutional and sustainability information was additionally collected through participant observation during field mentoring, comprising at least eight field visits over eight months, supplemented by remote consultation through WhatsApp groups. The complete intervention extended beyond installation of the filtration system to include education, technical capacity building, institutional development, and sustainability planning. As summarized in **Table 1**, the intervention was implemented through seven interconnected stages, with specific target groups and monitoring indicators used to document technical, educational, and institutional outcomes.

Table 1. Intervention stages, target groups, and data collected during the study.

Intervention stage	Target group/system	Indicators or data collected
Water-quality and healthy drinking water education	Caretakers, administrators, 20 senior students, and 25 junior students	Baseline understanding/competency assessment
Six-module, 24-h structured training	20 senior students	Attendance, competency assessment, and certification
Construction of the multi-stage filtration system	Filtration facility	One filtration unit with an installed capacity of 1,000 L/day
Pretest–posttest water-quality assessment	Source and treated water	Fourteen physical, chemical, and microbiological parameters and comparison with applicable drinking water standards
Establishment of the Drinking Water Management Unit	20 senior students	Institutional decree, organizational structure, and standard operating procedures
Development of the “Tahfidz Water” social entrepreneurship model	Drinking Water Management Unit	Business plan and proposed contribution of IDR 2,000/student/day
Field observation and mentoring	Drinking Water Management Unit	Eight visits over eight months and qualitative information on implementation and sustainability

As shown in Table 1, the intervention was designed as an integrated technical and capacity-building program rather than solely as the installation of a water-treatment unit. The initial educational and training activities developed basic knowledge and operational skills,

while construction and operation of the filtration system provided practical experience. The subsequent establishment of a Drinking Water Management Unit and development of the “Tahfidz Water” model were intended to strengthen institutional ownership and operational continuity. Field mentoring was used to observe implementation and identify practical issues affecting longer-term management of the system.

2.6. Data Analysis.

Water-quality data were analyzed descriptively by comparing each measured parameter before and after implementation of the filtration system. Absolute changes and percentage reductions were calculated where appropriate, and post-treatment values were compared with the applicable Indonesian drinking water quality standards. Because each water-quality parameter was represented by a single laboratory measurement for the pre-intervention and post-intervention conditions, the data structure did not provide replicated paired observations required for valid inferential statistical testing. Accordingly, p-values and statistical significance tests were not reported for the water-quality outcomes.

Student competency was also analyzed descriptively by comparing the aggregate percentage scores obtained before and after the training intervention. The change from a baseline score of 18% to a post-training score of approximately 85% was used to characterize improvement across the assessed competency domains. Because only aggregate pretest and posttest percentage scores were available, rather than individual paired observations for each of the 20 participants, inferential paired tests were not performed and statistical significance was not estimated.

Qualitative information obtained through field observations, mentoring activities, and consultations was analyzed descriptively to characterize institutional implementation, operational challenges, the development of the social entrepreneurship model, and factors relevant to program sustainability. The quantitative and qualitative findings were interpreted together to provide an integrated assessment of the technical, educational, and institutional outcomes of the intervention.

3. Results and Discussion

3.1 Quantitative Results: Differences in Water Quality Before and After Treatment

Laboratory analyses indicated clear changes in several water-quality parameters following implementation of the multi-stage filtration system. The most pronounced changes were observed for total dissolved solids (TDS), color, and total coliform, whereas several other parameters already complied with the applicable quality standards before treatment. Table 2 presents the complete comparison of the 14 physical, chemical, and microbiological parameters measured before and after filtration, together with their corresponding drinking water quality standards. decreased from 559 to 88 mg/L, corresponding to an approximately 84.3% reduction and bringing the treated water below the specified limit of 300 mg/L. This substantial decrease indicates that the treatment train was effective in reducing the measured concentration of dissolved constituents under the conditions evaluated in this study [15]. Color also decreased from 11 to 6, representing an approximately 45.5% reduction and bringing the treated water within the specified standard. The effectiveness of layered filtration can be influenced by the characteristics, arrangement, and interaction of the filtration media [16]. The microbiological

improvement was particularly important. Total coliform decreased from >100 CFU/100 mL before treatment to 0 CFU/100 mL after treatment, whereas *E. coli* remained undetected at both sampling stages. Iron and manganese concentrations were already below the specified limits before filtration and remained low after treatment [13, 17]. Temperature, turbidity, pH, nitrate, nitrite, residual chlorine, and fluoride also complied with the stated standards in both conditions. Thus, the main observed improvements were concentrated in TDS, color, and total coliform rather than across all 14 parameters.

Table 2. Water-Quality Characteristics Before and After Multi-Stage Filtration at PMBS Tahfidz Islamic Boarding School.

Parameter	Unit	Quality standard	Pretest	Posttest
Temperature	°C	Deviation ± 3	27.8	27.9
Total dissolved solids (TDS)	mg/L	<300	559	88
Turbidity	mg/L*	<3	0	0
Color	NTU*	10	11	6
Odor	–	Odorless	Odorless	Odorless
pH	–	6.5–8.5	7.87	7.66
Nitrate	mg/L	20	0	0
Nitrite	mg/L	3	0.04	0.03
Iron	mg/L	0.2	0.01	0.01
Manganese	mg/L	0.1	0	0
Residual chlorine	mg/L	0.2	0.02	0.01
Fluoride	mg/L	1.5	0.06	0.05
<i>Escherichia coli</i>	CFU/100 mL	0	0	0
Total coliform	CFU/100 mL	0	>100	0

3.2. Student Competency Before and After Training.

In addition to technical water-quality performance, the intervention was designed to strengthen students' capacity to operate and maintain the treatment system. All 20 senior students participated in the six-module training program with attendance of at least 90% and subsequently received competency certification. The aggregate competency score increased from 18% before training to approximately 85% after training, corresponding to an increase of approximately 67 percentage points. Knowledge transfer from the senior students to 25 junior students was also incorporated into the program to support continuity of technical skills within the institution. To provide a concise comparison of the principal technical and educational outcomes, Table 3 summarizes the major pretest–posttest changes in TDS, color, total coliform, and student competency. These indicators were selected because they exhibited the clearest changes following the intervention and represent both dimensions evaluated in the study: drinking water quality and student capacity.

Table 3. Summary of the Principal Pretest–Posttest Outcomes.

Indicator	Pretest	Posttest	Descriptive change
TDS (mg/L)	559	88	Decreased by 471 mg/L (84.3%)
Color	11	6	Decreased by 5 units (45.5%)
Total coliform (CFU/100 mL)	>100	0	Reduced to 0 CFU/100 mL
Student competency score (%)	18	≈85	Increased by approximately 67 percentage points

As summarized in Table 3, the intervention produced marked descriptive changes in the principal water-quality and competency outcomes. To provide a visual comparison of these

changes, Figure 1 presents the pretest and posttest values for TDS, color, total coliform, and student competency. The figure highlights the reduction in the three selected water-quality indicators and the corresponding increase in student competency following the intervention. Because these indicators are expressed in different units, the figure should be interpreted as a visual summary of the direction and magnitude of change rather than as a direct comparison among indicators.

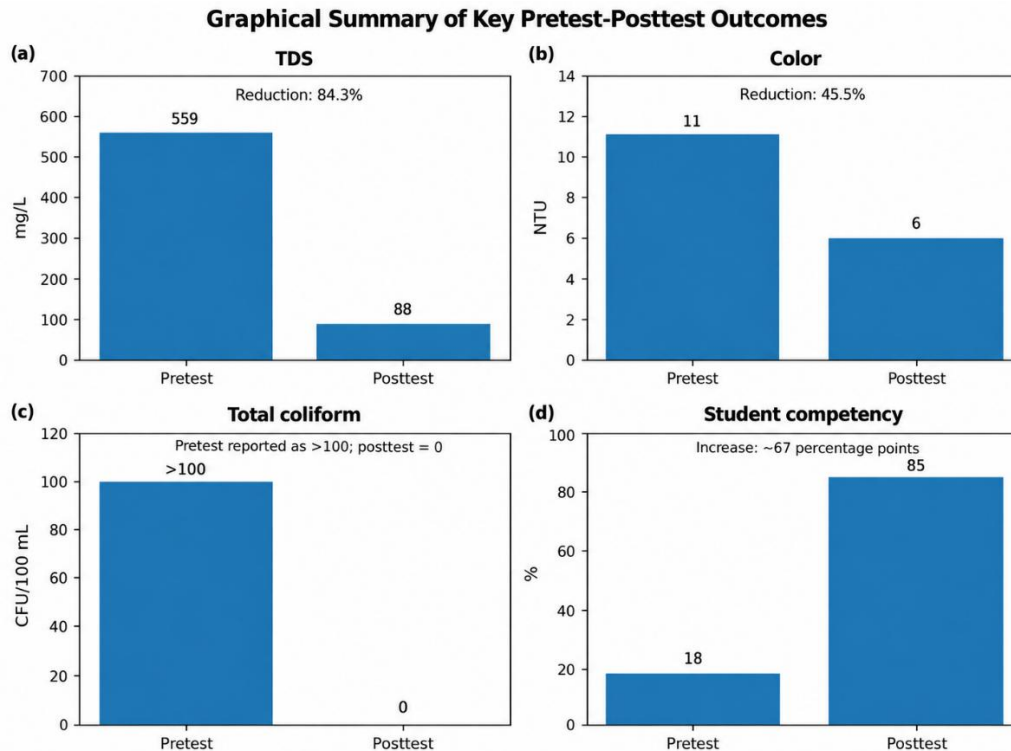


Figure 1. Graphical Summary of Key Pretest-Posttest Outcomes for Water Quality And Student Competency.

3.3. Integrated Technical and Capacity-Building Outcomes.

The observed water-quality improvements can be interpreted in relation to the sequential treatment mechanisms incorporated into the filtration system. Polypropylene and silica media primarily provided physical filtration, cation-exchange resin contributed to the removal of ionic constituents, activated carbon provided adsorption capacity for selected dissolved compounds, and UV irradiation served as the final microbiological disinfection step. The reduction in TDS from 559 to 88 mg/L indicates substantial removal of dissolved constituents; however, the contribution of each individual treatment medium cannot be determined from the present study because intermediate samples were not collected between treatment stages. Therefore, the observed reduction should be attributed to the integrated treatment train rather than specifically to cation resin or activated carbon. This interpretation is more appropriate than direct comparison with reverse-osmosis or biosand filtration systems, which operate through different treatment mechanisms [18, 19].

The reduction of total coliform from >100 to 0 CFU/100 ml was also an important microbiological outcome because coliform bacteria are widely used as indicators of microbial contamination in drinking water [20]. The observed post-treatment result was likely associated with the combined effects of upstream filtration and final UV disinfection. UV treatment is particularly relevant for microbiological control when an adequate irradiation dose and suitable

operating conditions are maintained [21, 22]. Nevertheless, repeated microbiological sampling would be required to establish whether this level of treatment performance can be maintained consistently over time.

The educational component complemented these technical improvements. The increase in competency score from 18% to approximately 85% indicates substantial improvement in the assessed knowledge and practical competency domains following the learning-by-doing intervention. Students were directly involved in filtration-system assembly, operation, maintenance, and water-quality management. Such participation is important because the long-term functionality of decentralized water systems depends not only on treatment performance but also on the ability of local users to operate and maintain the technology [23]. Participatory approaches can additionally strengthen environmental awareness and facilitate the transfer of practical knowledge within institutional communities [9, 24].

The establishment of a student-based Drinking Water Management Unit and the proposed “Tahfidz Water” cost-recovery model further extended the intervention beyond technical installation. The management unit provided an organizational mechanism for operation, maintenance, administration, quality control, and knowledge transfer, while the proposed financial mechanism was intended to support recurring operational and filter-replacement costs. These developments indicate emerging institutional ownership [5, 6, 14]. However, because long-term operational continuity and financial performance were not quantitatively monitored, they should be interpreted as implementation and sustainability-supporting outcomes rather than evidence of established long-term sustainability.

3.4. Study Limitations.

Several limitations should be considered when interpreting these findings. First, the one-group pretest–posttest design did not include a control group; therefore, the observed changes cannot be attributed exclusively to the intervention. Second, the study was conducted at a single Islamic boarding school with a relatively small intervention group, limiting broader generalizability. Third, each water-quality parameter was represented by only one laboratory value at each measurement stage, preventing assessment of temporal variability and inferential statistical testing. Similarly, student competency was available as aggregate percentage scores rather than individual paired pretest–posttest observations. Future studies should therefore include repeated water sampling, individual-level competency data, longer monitoring periods, and comparison or control groups across multiple Islamic boarding schools. Such designs would enable inferential statistical analysis and provide stronger evidence regarding treatment performance, competency development, operational durability, and long-term sustainability.

4. Conclusions

The implementation of an appropriate-technology multi-stage filtration system at PMBS, West Koya, Jayapura City, was associated with clear descriptive improvements in drinking water quality and student competency. Laboratory results showed that TDS decreased from 559 to 88 mg/L, color decreased from 11 to 6, and total coliform decreased from >100 to 0 CFU/100 ml. These changes indicate that the filtration system improved key physical and microbiological water-quality parameters and enabled the treated water to meet the specified drinking water quality standards. The capacity-building component also increased the

aggregate competency score of 20 senior students from 18% before training to approximately 85% after training. Through hands-on training, students developed practical competencies in assembling, operating, monitoring, and maintaining the filtration system. The establishment of a student-based Drinking Water Management Unit and the “Tahfidz Water” social-enterprise model further provided an institutional framework to support continued operation and maintenance. Overall, integrating appropriate filtration technology with student capacity building offers a potentially applicable model for decentralized drinking water management in Islamic boarding schools facing similar water-supply challenges. However, because the study used a one-group pretest–posttest design without a control group, the observed improvements should not be interpreted as definitive causal effects of the intervention. Future studies should employ comparison or control groups, repeated water-quality measurements, and individual paired pretest–posttest competency data to enable more rigorous statistical evaluation. Longer-term monitoring is also needed to evaluate filtration-media performance, microbiological safety, maintenance requirements, operational costs, and the financial sustainability of the “Tahfidz Water” model. Routine water-quality monitoring and adequate funding for system maintenance and filter replacement are essential to maintain treatment performance and support the long-term sustainability of the student-managed drinking water system.

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Author Contribution

All authors contributed equally to the conceptualization, methodology, data collection, data analysis, writing, supervision, and funding acquisition of this research. The final manuscript has been reviewed and formally approved by all participating authors.

Competing Interest

The author declares no conflict of interest.

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