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WASTEWATER TREATMENT OF BATIK MICRO, SMALL, AND MEDIUM ENTERPRISES FOR CLEAN WATER CONSERVATION

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Abstract

Batik wastewater generated by micro-scale industries typically contains high organic loads, intense coloration, and fluctuating pH, exceeding national discharge limits. This study aims to design, install, and evaluate a simple pilot-scale wastewater treatment plant (WWTP) using a coagulation–filtration–adsorption process for UMKM Batik Ulur Wiji in Indonesia. Wastewater quality was analyzed before and after treatment for pH, BOD, COD, TSS, TDS, turbidity, and color referring to Indonesian Ministry of Environment Regulation No. 5/2014. The results show a substantial improvement in water quality, with COD reduced from 857 to 112 mg/L and BOD from 358 to 68 mg/L. Turbidity decreased from 218 to 14 NTU, and color removal was visually significant. The treated effluent met key parameters for non-potable reuse. A partner satisfaction survey revealed increased environmental awareness, full operational understanding of WWTP, and long-term commitment to system use. This study demonstrates that simple low-cost treatment units are effective for batik wastewater management in micro-industries and provide a replicable model for community-based environmental interventions.

Keywords: Batik Wastewater, Circular Economy, Sustainability, Wastewater Treatment Plant, Water Conservation

INTRODUCTION

Batik is a significant part of Indonesian cultural heritage and is widely produced by micro, small, and medium enterprises (MSMEs) that continue to demonstrate resilience in adapting to global challenges. The production process—including dyeing, washing, and wax removal—generates complex liquid waste with hazardous properties. This waste contains dyes, wax residues, auxiliary chemicals, and cations that may degrade soil and water quality if not treated properly (Apriyani, 2018; Juliani et al., 2021; Kiswanto et al., 2019; Safamaura & Afany, 2025). Among the various waste types, liquid waste is the most dominant and presents the greatest environmental risk due to its persistent pollutants. Numerous studies have reported that batik wastewater typically shows high turbidity, total suspended solids (TSS), total dissolved solids (TDS), and chemical oxygen demand (COD), making it difficult to degrade naturally (Kiswanto et al., 2019; Melfazen et al., 2022; Permatasari et al., 2023). The predominance of liquid waste

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in batik production makes wastewater treatment a critical issue, particularly due to its content of recalcitrant dye-based pollutants (Apriyani, 2018). These pollutants contribute to high TDS, TSS, and COD levels, which limit natural degradation processes and require targeted treatment technologies (Daud et al., 2023). At the Ulur Wiji Muda Berdaya (Ulur Wiji) MSME, each production step—including pre-mordanting with alum or soda ash, dyeing with natural colorants, and wax removal using soda ash—generates wastewater with considerable pollutant loads. Recent research also shows that natural dyes still pose environmental and health risks when released into aquatic systems (Kumari et al., 2023). These findings reinforce the need for MSMEs to prioritize wastewater treatment to maintain their reputation as environmentally responsible producers.

A wide range of technologies have been applied to treat batik wastewater. Chemical methods such as coagulation and flocculation are effective in reducing dye concentrations, while physical processes including adsorption with activated carbon or natural materials, photocatalysis further lower pollutant levels (Fujishima & Zhang, 2006; Pradelia et al., 2025; Prameswari & Kusuma, 2021). Others methods have been evaluated, including chemical approaches such as coagulation and membrane filtration, physical processes such as electrochemical treatment, electrolysis, and adsorption, and biological treatments using plants, bacteria, and fungi (Afifah, 2022; Ali et al., 2019; Fidiastuti et al., 2022; Juliani et al., 2021; Pradelia et al., 2025; Wang et al., 2019). Electrochemical treatment uses electric current to degrade dyes, reduce metal ions, and separate suspended particles, making it effective for removing color and persistent pollutants. Adsorption captures contaminants on solid surfaces such as activated carbon or natural materials, efficiently removing color, organic compounds, and heavy metals. Biological treatment relies on microorganisms to break down organic pollutants into harmless products. Each method offers different removal efficiencies, and the selection of technology must consider wastewater characteristics, technical requirements, and the operational capacity of MSMEs.

Coagulation–flocculation–adsorption is an effective combined method for treating batik wastewater with high pollutant loads. Many researchers have published this method applicable to many areas (Abdillah & Mirwan, 2024; Koagulan et al., n.d.; Ladini et al., 2024; Lucas et al., 2025; Łukasiewicz, 2025; Pradelia et al., 2025; Prameswari & Kusuma, 2021; Sheng et al., 2023). During coagulation and flocculation, chemical coagulants are added to aggregate fine particles, dyes, and dissolved organic compounds into larger flocs that can be easily separated. This stage significantly reduces turbidity, color, and concentrations of TSS and COD. The process is then followed by adsorption, in which media such as activated carbon or zeolite capture remaining dyes, metal ions, and organic compounds that are not removed in the initial stage. Integrating these methods provides better overall performance than using a single treatment approach, as it targets multiple pollutant types simultaneously, improves water clarity, and increases the potential for wastewater reuse.

Implementing simple, efficient, and MSME-appropriate wastewater treatment systems is essential for improving environmental performance, conserving water resources, and supporting community well-being. In this context, the present study focuses on developing and implementing a practical wastewater treatment system for the Ulur Wiji Muda Berdaya MSME that aligns with technical feasibility and local operational capacity. The system integrates coagulation–flocculation–adsorption to target pollutants commonly found in batik wastewater while maintaining low cost, ease of operation, and minimal maintenance. The objectives of this work are threefold: (i) to characterize the wastewater generated during batik production, (ii) to design and install a treatment unit suitable for MSME-scale application, and (iii) to evaluate its performance in reducing key environmental parameters such as turbidity, color, Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD). By emphasizing appropriate technology, this study aims to provide a replicable model for batik wastewater management that supports regulatory compliance, promotes water conservation, and contributes to sustainable industrial practices within the MSME sector.

IMPLEMENTATION METHOD

This Community Service Program was conducted at the Batik Ulur Wiji SME in Pandankrajan Village, Mojokerto Regency. The program responded to wastewater issues arising from batik production and targeted artisans committed to improving environmental performance. Technical assistance and hands-on training were provided to support the implementation of a simple, appropriate-technology wastewater treatment plant (WWTP).

Program activities consisted of wastewater sampling and characterization, system design, installation, and performance testing. Key wastewater parameters (pH, color, turbidity, TSS, TDS, COD, and BOD) were analyzed as the basis for designing a WWTP comprising coagulation–filtration–adsorption and microfiltration units. Coagulants and activated carbon were used to remove color, suspended solids, and dissolved contaminants, while microfiltration improved effluent clarity.

Evaluation was conducted by comparing wastewater quality before and after treatment. The effectiveness of the system was assessed based on reductions in physical and chemical parameters and the potential reuse of treated water for washing or irrigation.

RESULTS AND DISCUSSION

The condition of the wastewater at Ulur Wiji SME exhibited the typical characteristics of batik effluent, including dark coloration and a high content of organic matter, as shown in Table 1. The intense color of the wastewater originates from residual dyes that are not absorbed by the fabric during the dyeing process. Although Batik Ulur Wiji SME is known for promoting a sustainable lifestyle and primarily using natural dyes, the resulting dye waste remains an issue that requires proper treatment. The natural dye materials used at the SME include jolawe wood for producing yellow tones, tegeran wood for bright yellow shades, mahogany wood for red and mixed black hues, and other natural dye sources (Mohammad & Hermansyah, 2024).

The wastewater also contains high levels of organic matter, as indicated by BOD and COD values that exceed the textile wastewater quality standards specified in the Indonesian Ministry of Environment Regulation No. 5 of 2014. A comparison between the initial analytical results wastewater samples and the corresponding quality standards is presented in Table 1.

Table 1. A comparison between the initial analytical results of the wastewater samples and the applicable wastewater quality standards

Parameter	Standard*)	Analysis	Unit
pH	6,0 – 9,0	4,0 – 11 (varied)	-
BOD	60	358	mg/L
COD	150	857	mg/L
TDS	-	773	ppm
TSS	-	61,1	mg/L
Turbidity	-	218	NTU

Note: *based on the Indonesian Ministry of Environment Regulation No. 5 of 2014 for the textile industry.

The high organic content in the initial wastewater samples originates from dyeing auxiliaries, phenolic compounds and their derivatives released during the wax removal process, as well as the use of soaps or detergents during washing. The dyeing process often requires mordants to fix the color onto the fabric, and these auxiliary substances may also end up in the wastewater, contributing to its organic load (Afifah et al., 2022). The wax removal stage aims to dissolve the wax used as a color resist. This process is carried out using hot water and detergents, causing dissolved wax and chemical residues to enter the wastewater stream. Dissolved wax, detergents, and other chemical residues contribute to increased BOD and COD levels in batik wastewater (Fidiastuti et al., 2022)

The most common treatment methods for reducing dyes and organic matter in wastewater involve combinations of physical and chemical processes. Filtration and coagulation–flocculation with chemical additives have been reported as the most effective methods, achieving more than 70% reduction in organic content (Handayani et al., 2025). Accordingly, the WWTP (IPAL) design developed for the wastewater generated by Batik Ulur Wiji includes coagulation–filtration–adsorption units. The system is also equipped with a neutralization unit to address the wide pH range observed in the initial wastewater measurements, as well as a microfiltration unit to enhance the removal of fine particulates.

Figure 1 illustrates the installation process of the simple WWTP unit conducted by the Politeknik Negeri Malang PPM team. The system utilizes blue plastic drums as the main reactors, where coagulation, filtration, and adsorption occur simultaneously. The installation process also includes arranging pipes, fittings, and supporting components required to facilitate wastewater treatment within the main reactor. Several considerations were addressed during installation, including reactor placement, pipe and joint installation, and operational context. The main reactor (blue drum) was positioned in an open yet partially sheltered area to allow convenient maintenance and monitoring while avoiding direct exposure to rainfall. This setup ensures accessibility for routine operation and maintains adequate air circulation.

Figure 1 also shows vertically installed PVC pipes serving as both the inlet and outlet for the wastewater. These pipes are essential for regulating the flow of wastewater through the treatment system. Ensuring proper wastewater flow is a critical factor in the effectiveness of batik wastewater treatment, as depicted in Figure 2. This small-scale wastewater treatment unit (WWTP) is designed specifically for household and micro– to medium-scale industries, making it suitable for enterprises such as UMKM Batik Ulur Wiji. The system enables wastewater containing dyes and organic compounds to be treated in a more environmentally friendly manner before being released into the environment.

Figure 1. Installation of IPAL unit

Figure 2. Checking waste flow

The installed WWTP demonstrated a significant improvement in wastewater quality. The color intensity decreased markedly after passing through the coagulation and adsorption units. The previously extreme pH values were successfully neutralized to meet the regulatory standards. In addition, the microfiltration process enhanced water clarity, allowing the treated effluent to be reused for fabric washing or for irrigation in the surrounding area. A comparison of wastewater quality before and after treatment is presented in Table 2. Figures 1 and 2 also show several individuals working collaboratively during the installation process, including pipe connection, position alignment, and the possible placement of filter media inside the drum units. This indicates that the installation of the WWTP requires coordinated teamwork to ensure all components are properly assembled. The involvement of the UMKM Batik Ulur Wiji team also facilitates effective technology transfer, enabling the partners to operate and maintain the WWTP system reliably.

The installation of WWTP continued with site arrangement, including floor preparation as shown in Figure 3. Floor construction is an essential aspect of the installation process because it provides structural support and stability for the entire system. The floor must be able to withstand the load of the reactors (plastic drums) filled with wastewater during treatment. A concrete floor enhances stability and safety, minimizing the risk of shifting or tilting that could disrupt the wastewater flow. Proper floor conditioning also prevents leakage or seepage of wastewater into the soil or groundwater, which would constitute a serious environmental violation due to the potential contamination of drinking water sources, soil, and nearby ecosystems.

Tabel 2. A comparison between the before and after analytical wastewater treatment

Parameter	Standard*)	Before Treatment	After Treatment	Unit
pH	6,0 – 9,0	4,0 – 11 (varied)	6-8	
Color	-	Dark	Significantly decrease	-
Odor	-	Stingky	Almost odorless	-
Potential Usage	-	Unpotential	Potential	-=
BOD	60	358	68	mg/L
COD	150	857	112	mg/L
TDS	-	773	343	ppm
TSS	-	61,1	1,8	mg/L
Turbidity	-	218	14	NTU

Figure 4 shows the condition of the batik wastewater prior to treatment in the WWTP unit. Visually, the wastewater appears dark and intensely colored, dominated by a greenish-black hue. This color originates from synthetic dyes used in the batik dyeing process, particularly textile dyes that are resistant to natural degradation. In addition to the strong coloration, the wastewater also appears turbid, indicating the presence of suspended particles that contribute to high turbidity levels. This condition reflects the presence of organic and inorganic compounds, as well as residual chemicals such as caustic soda, naphthol dyes, salts, and other dyeing auxiliaries (Fidiastuti et al., 2022). These substances affect not only the aesthetic quality of the water but also pose environmental risks if discharged without treatment. The intense color and high turbidity correspond to elevated COD (857 mg/L) and BOD (358 mg/L) values commonly found in untreated batik wastewater (Apriyani, 2018) . Therefore, the initial condition shown in the figure serves as an essential baseline for evaluating the effectiveness of the designed WWTP.

Figure 5 presents the condition of the batik wastewater after treatment using the WWTP system equipped with zeolite, activated carbon, and TiO_2 photocatalyst media. Visually, the treated wastewater appears significantly clearer compared to the initial state. The previously intense color has noticeably diminished, and turbidity levels have decreased substantially. These physical changes indicate that the treatment system successfully reduced dye concentration and suspended solids. Zeolite and activated carbon function to adsorb metal ions, colorants, and organic compounds, while the TiO_2 photocatalytic process aids in degrading complex organic pollutants into simpler, more environmentally benign compounds (Afifah et al., 2022; Fujishima & Zhang, 2006).

Figure 3. Floor arrangement around the installed WWTP unit

Figure 4. Wastewater before WWTP treatment

Figure 5. Wastewater after WWTP treatment

The improvements observed in the treated wastewater provide preliminary evidence that the installed WWTP unit operates effectively in enhancing batik wastewater quality. Furthermore, the increased clarity suggests potential for water reuse in certain non-potable applications, although further assessment through parameters such as COD, BOD, TSS, and pH remains necessary. These results are consistent with findings from Pardede et al. (2025), which demonstrate that adsorption–filtration-based treatment systems are effective in reducing pollutant loads in textile wastewater (Pardede et al., 2025). The implementation of this WWTP offers positive environmental impacts by reducing pollution risks, minimizing the use of fresh water through reuse of treated effluent for washing or irrigation, and strengthening Ulur Wiji's reputation as an environmentally responsible MSME. Figure 6 documents the collaboration between the PPM team from Politeknik Negeri Malang and the UMKM Batik Ulur Wiji partners.

Figure 6. The PPM team from the State Polytechnic of Malang with the Ulur Wiji partner

Survey results from partners involved in the Community Service Program (PPM) show that the activity produced clear positive impacts. Figure 6 shows the PPM team during visit to Ulur Wiji. Respondents stated that the program provided solutions to their problems, with the PPM team actively offering assistance. Overall, partner satisfaction with the program was very high, indicating that the PPM activities contributed to partner development and improved their competitiveness. All respondents gave a score of 5 (very satisfied/very well understood) for every statement. This indicates that partners perceived the program as delivering real solutions to their challenges. The highest scores were given for team responsiveness, demonstrating effective, communicative, and needs-based interactions between the PPM team and the partners. The frequency of assistance was considered appropriate, meaning the schedule was viewed as balanced and not excessive. Respondents also reported noticeable improvements in independence, knowledge, and technical skills. Finally, overall satisfaction was rated very high, confirming that the PPM activities successfully met partner needs and expectations without any complaints or critical feedback.

Every statement received a score of 5 from all respondents. Participants fully understood the environmental hazards of batik wastewater, indicating improved awareness of environmental issues. Outreach and education on wastewater management were considered highly beneficial, showing that the materials provided were relevant and practical to implement. Participants also understood how the installed WWTP system operates, meaning the technology was not only theoretically understood but could also be operated independently. Moreover, the highest scores for long-term commitment to using the WWTP reflect the program’s sustainable impact. With these perfect results, the wastewater management component of the program can be considered highly successful and effective in achieving its objectives.

The treatment of batik wastewater using a simple coagulation–filtration–adsorption system aligns closely with the Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation) and SDG 12 (Responsible Consumption and Production). Implementing a wastewater treatment unit at the Batik Ulur Wiji micro-enterprise demonstrates a concrete effort to reduce water pollution, improve environmental quality, and enable non-potable water reuse. In addition, partner training and awareness initiatives strengthen environmental responsibility and promote more sustainable production practices. With its low cost and simple design, this model can be replicated in other micro-industry communities, supporting inclusive, community-based progress toward the SDGs.

CONCLUSION

The study aimed to develop and evaluate a simple, low-cost coagulation–filtration–adsorption system for treating batik wastewater generated by micro-scale enterprises. The installed WWTP significantly improved effluent quality, reducing COD from 857 to 112 mg/L, BOD from 358 to 68 mg/L, and turbidity from 218 to 14 NTU, while stabilizing pH within the permitted regulatory range. These results demonstrate that an integrated adsorption-based treatment unit can effectively reduce pollutant loads in batik effluent and enable water reuse for non-potable applications. This work provides a practical and replicable model for wastewater management in community-based batik industries, contributing to sustainable water conservation practices. However, further studies are recommended to optimize adsorbent regeneration, evaluate long-term system performance, and analyze treatment efficiency under continuous-flow operating conditions.

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