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Promoting Green Chemistry in Cultural Heritage Industry: Sustainable Batik Waste Management at Kampung Batik Giriloyo, Yogyakarta

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Abstract.
The traditional batik industry in Kampung Batik Giriloyo, Yogyakarta, serves not only as a center for cultural heritage but also as a vital driver of the local economy. However, its artisanal production processes, particularly the use of wax (malam) and synthetic dyes, pose environmental risks that are often overlooked. This community-based study investigates how waste generated from batik production is managed and evaluates the effectiveness and sustainability of existing practices. Field observations and semi-structured interviews with batik artisans and community leaders revealed that Giriloyo has established a localized waste treatment system with clear standard operating procedures. Waste wax is partially recycled and resold, while dye effluents undergo coagulation with alum and phytoremediation using water hyacinths. Although no significant environmental complaints have emerged from nearby agricultural communities, the study identifies key areas for improvement, particularly the low efficiency of wax reuse (under 10%) and the absence of advanced dye treatment stages. Anchored in green chemistry principles, especially prevention, safer auxiliaries, and waste reduction. This study recommends affordable technological upgrades and strategic partnerships to enhance environmental performance. The findings offer a replicable model for culturally rooted, eco-conscious craft industries in rural settings. This paper contributes to the growing discourse on sustainable heritage economies and highlights the potential of local innovation in achieving both economic resilience and environmental stewardship.
Keywords: *Batik; Batik Giriloyo; Local economic; Green Chemistry; Sustainable waste treatment.*

I. INTRODUCTION

Kampung Batik Giriloyo, located in Wukirsari Village, Bantul, Yogyakarta, is one of Indonesia's prominent centers of traditional hand-drawn batik (batik tulis), renowned for preserving the authenticity of classic batik motifs and techniques (**Fig. 1**). Historically rooted in the Mataram

Islamic kingdom, Giriloyo has developed as a cultural heritage site where batik is an economic activity and a medium for intergenerational cultural transmission (Anggarani Pribudi, 2020). The preservation and revitalization of batik traditions in Giriloyo have been strongly supported by local community cooperatives, which organize training, exhibitions, and marketing initiatives for artisans. The active involvement of village stakeholders and artisan groups has fostered a shared sense of ownership and cultural pride. Additionally, the local government of Bantul Regency has played a key role by promoting Giriloyo as a cultural tourism destination, providing infrastructure support, and facilitating access to regional and national markets. To further strengthen cultural continuity, local batik knowledge has also been incorporated into the local content curriculum in secondary schools in the Bantul area, allowing younger generations to learn the art and philosophy of batik from an early age. These collaborative efforts have helped position Giriloyo as a model for culture-based economic development in Yogyakarta.

Figure 1. Canting process of batik in Giriloyo

Over the decades, the development of batik in Giriloyo has faced multiple challenges, ranging from competition with printed batik (batik cap and batik printing) (Agus Dwi Cahya et al., 2021) to fluctuating market demands. However, the most severe disruption came during the COVID-19 pandemic, which significantly reduced tourism activities and batik sales, threatening the livelihoods of many artisans. In the aftermath of the pandemic, the community of Giriloyo has shown remarkable resilience by revitalizing production, adopting online marketing strategies (Utomo & Susanta, 2020), and initiating collaborative training programs to improve quality and competitiveness (Utami & Cahyana, 2021). One of the notable driving forces behind this revival was the active role of digital content creators and YouTubers who featured Giriloyo's batik-making process, cultural history, and artisan stories on their platforms. These video contents, often showcasing behind-the-scenes footage of traditional wax-resist dyeing techniques, helped attract wider audiences and educated viewers about the value of handmade batik. Several viral videos introduced Giriloyo as an authentic batik village, sparking renewed interest from both domestic and international viewers. Collaborations between artisans and content creators also enabled product promotion through social media, increasing online sales and opening new market opportunities. As a result, the visibility of Giriloyo batik expanded beyond local tourism circuits, establishing a digital presence that continues to support the village’s economic and cultural revival. One of the key

post-pandemic recovery efforts has been the drive to improve productivity and sustainability in batik production. Local initiatives have begun to explore more environmentally conscious practices, including reusing waste wax for subsequent production cycles, reducing synthetic dye use, and adopting basic principles of green chemistry (Safitri & Rahmayanti, 2020). These efforts not only aim to reduce environmental impacts but also to enhance material efficiency and reduce production costs (Ajizah et al., 2021), thereby increasing artisans' profit margins and ensuring long-term sustainability of the craft.

The batik artisans of Giriloyo, mostly comprised of women from local households, have long relied on traditional techniques that involve the use of wax and synthetic dyes. While these practices are vital for maintaining the quality and identity of original batik, they also generate environmental concerns, particularly regarding the disposal of residual wax and chemical dye waste into the local ecosystem. In the traditional batik process, molten wax (malam) is applied to fabric using a small copper tool called *canting*, which allows artisans to draw intricate patterns by hand. The wax acts as a resist material, preventing dye from penetrating the fabric in specific areas. After the fabric is dyed, the wax is removed by boiling or soaking the cloth in hot water, which melts the wax and separates it from the textile fibers called *lorot* (Karlina et al., 2024). This wax removal process produces a significant amount of wax-contaminated wastewater, often discharged directly into the ground or drainage systems without proper treatment. Moreover, much of the used wax becomes mixed with dyes and fabric residues, making it difficult to recycle or reuse without purification. Over time, the accumulation of wax waste in open environments can lead to clogged water channels, soil impermeability, and increased chemical load in nearby ecosystems. In some cases, improper disposal practices such as burning used wax release harmful substances into the air, contributing to air pollution and posing health risks to local communities (Utama & Fitriyani, 2022). These issues underscore the urgent need to introduce environmentally responsible practices, including wax recovery and recycling methods, as part of a broader push toward green chemistry in traditional batik industries.

In response to these concerns, Kampung Batik Giriloyo has taken proactive steps by establishing a small-scale batik waste management installation to handle both wax and dye residues before they are released into the environment. The treatment process includes a coagulation method using alum to remove colorants from wastewater and a simple filtration system to reduce chemical content (Islam & Mostafa, 2020; Aragaw & Bogale, 2023). In parallel, artisans have also begun practicing wax recovery, where used wax is collected, filtered, and reused for subsequent batik production. The reuse of batik wax waste aligns with the principles of green chemistry, particularly Principle 1 (Prevention), which emphasizes minimizing waste at its source, and Principle 5 (Safer Solvents and Auxiliaries), which promotes the responsible use and recycling of auxiliary substances (de Marco et al., 2019). By recovering and reusing wax, the batik production process becomes more sustainable, reducing the demand for new raw materials and mitigating environmental pollution. However, current recovery methods remain rudimentary, and the efficiency of wax recycling is still below 10%, due to the high impurity levels and degradation of wax quality after repeated use. This low efficiency poses a challenge for artisans, as it limits the economic viability of reuse and does not yet significantly reduce dependence on fresh raw materials. Therefore, there is an urgent need to improve the technical effectiveness of wax purification processes, both to minimize environmental

burden and to enhance production cost efficiency, in alignment with sustainable and green chemistry principles.

This article presents the findings of a community engagement and international service-learning project conducted in Kampung Batik Giriloyo, focusing on the observation and analysis of local waste management practices. It highlights the potential and challenges in integrating green chemistry principles into the traditional batik industry and provides practical recommendations to strengthen environmental awareness, economic resilience, and cultural sustainability in heritage-based industries.

II. METHODS

This community engagement program employed a qualitative approach using observational study and semi-structured interviews to explore and understand the existing batik production practices and waste management efforts in Kampung Batik Giriloyo, Wukirsari Village, Bantul, Yogyakarta.

2.1. Observational Study

Field observations were conducted directly at multiple home-based batik production units within the Giriloyo area. The purpose of this observation was to document the step-by-step batik-making process particularly the use of wax and synthetic dyes, and identify critical points where waste is generated. Observations focused on material input, production workflow, wax application and removal stages, and current practices for waste disposal and recycling. Notes, photos, and video documentation were taken to support data collection and provide visual references for subsequent analysis.

2.2. Semi-Structured Interviews

To gain deeper insights into local practices and challenges, semi-structured interviews were carried out with key stakeholders, including batik artisans, workshop owners, and administrators of the Giriloyo Batik Community. The interviews covered topics such as the economic role of batik production in the community, knowledge and perceptions of environmental issues, current waste management strategies, and initiatives toward sustainable practices. The flexible format of the interviews allowed for open-ended discussions while still ensuring consistency across participants. The combination of direct observation and dialogue enabled the research team to obtain both practical and contextual understanding of how traditional batik practices intersect with environmental and sustainability concerns. Data collected from these methods informed the identification of key issues and the formulation of recommendations for improving the environmental performance of batik production through green chemistry approaches.

III. RESULT AND DISCUSSION

3.1. Wax and Dye Waste Management

Field observations and interviews revealed that Kampung Batik Giriloyo has made notable progress in addressing environmental concerns associated with batik production. The village has established a waste treatment installation and formulated standard operating procedures (SOPs) for handling both wax and synthetic dye waste (**Fig. 2**). This facility, though small in scale, demonstrates the community's commitment to environmentally responsible practices. In particular, the management of waste wax involves a recovery process in which the wax is collected after use,

partially purified, and then reused in subsequent production cycles. A portion of the recovered wax is also sold to third-party buyers, providing a minor additional income stream for the artisans.

Figure 2. *lorot* process: reducing wax and dyes from batik

Despite these promising efforts, several limitations remain. The current wax recovery process is still relatively basic, with minimal refinement technology, resulting in a reuse efficiency rate below 10%. Much of the reused wax is of lower quality, limiting its suitability for fine batik work, which relies on precise line detail and controlled flow characteristics. Furthermore, the absence of a standardized purification system means that recovered wax may still contain chemical residues or impurities that affect both the aesthetic quality of the fabric and the environmental impact when reused or disposed of improperly.

These findings suggest that while the existence of a structured waste management system is commendable, there is a clear need for technological enhancement and capacity building in order to increase both the effectiveness and efficiency of the wax recovery process. Investment in simple but scalable purification technologies such as multi-stage filtration, sedimentation, or eco-friendly solvent-based separation could significantly improve the quality of recycled wax and reduce dependence on new raw materials. Encouraging collaboration with academic institutions or green technology providers may also support the development of more sustainable production models in the future. In addition to wax waste management, the community of Kampung Batik Giriloyo has also implemented a basic system for handling liquid dye waste, which primarily originates from the rinsing and dyeing stages of batik production. The existing system involves the collection of dye-contaminated wastewater into a dedicated treatment installation. In this setup, alum (tawas) is added as a coagulant to promote the sedimentation of color particles and clarify the wastewater. The partially treated water is then channeled into a control pond planted with water hyacinths (Eichhornia crassipes), which serve as natural phytoremediators due to their ability to absorb certain pollutants. While this method reflects an encouraging community-led effort to mitigate the environmental impact of batik production, it remains limited in scope and efficacy. The treatment process lacks crucial stages such as chemical oxidation, activated carbon filtration, or biological treatment that are typically required to meet industrial wastewater standards particularly for synthetic dye effluents, which are often resistant to degradation and can persist in the environment. Furthermore, the volume and retention time in the current installation may be insufficient to ensure complete decontamination, especially during periods of high production.

The presence of a localized wastewater management system demonstrates environmental awareness and initiative, but the current practices do not yet meet the standardized benchmarks for industrial dye waste treatment. There is a pressing need for upgrading both the quality and capacity of the wastewater treatment infrastructure to align with national and international environmental standards. Doing so will enhance environmental safety and strengthen the long-term sustainability and social responsibility of Giriloyo's culture-based economy.

3.2. Indications of environmental pollution

In reviewing the current waste management practices in Kampung Batik Giriloyo, it is important to consider the environmental risks associated with batik industrial waste, particularly wax residues and synthetic dye effluents. Although initial treatment steps have been implemented, the potential for environmental contamination remains, especially considering the geographical location of the waste management installation situated within a rice field area that is closely tied to local agriculture system. Wax waste, when not properly managed, can contribute to soil hydrophobicity by forming a thin, impermeable layer that inhibits water infiltration and gas exchange. This condition can reduce soil fertility and adversely affect crop productivity. Moreover, wax that contains residual solvents or degraded hydrocarbons may leach into the soil or nearby water bodies, contributing to chemical accumulation and toxic effects on soil microbiota and aquatic organisms (Hidayati et al., 2024; Goswami et al., 2024).

Synthetic dye effluents, particularly those based on azo and anthraquinone structures, pose even greater ecological concerns. These dyes are resistant to natural degradation, can be toxic, mutagenic, or carcinogenic, and persist in soil and water environments for extended periods. When dye-laden wastewater infiltrates agricultural areas, it can alter soil pH, inhibit enzymatic activity, and impair plant growth (Phang et al., 2022; Lellis et al., 2019). Additionally, colored effluents reduce light penetration in water bodies, disrupting aquatic ecosystems and photosynthetic organisms (Islam et al., 2025). Given the proximity of the wastewater ponds to irrigated rice fields, there is a significant risk of leaching, overflow during heavy rain, or surface runoff, which could carry untreated or partially treated pollutants into agricultural zones and groundwater reserves. Without the integration of more advanced and standardized wastewater treatment systems, such exposure may lead to bioaccumulation of harmful substances in crops, affect food safety, and ultimately threaten both environmental and human health (Shakir et al., 2017). These findings highlight the urgent need for ecological risk assessment and technical improvement in Giriloyo's waste management system to ensure that batik production remains compatible with sustainable environmental and agricultural practices.

Despite the potential risks associated with batik industrial waste, observations and on-site interviews indicate that local farmers or residents in the surrounding area have raised no significant environmental complaints. The proximity of the batik production and wastewater treatment units to agricultural fields, particularly rice paddies, has not led to observable damage or public concern in recent years. In fact, according to interviews with local community leaders and batik cooperative members, the presence of the batik industry is generally viewed as harmonious with the village's agricultural life. Furthermore, independent studies conducted over the past few years by local universities and environmental agencies have reported that the current waste treatment system despite its simplicity has managed to prevent direct contamination of the surrounding ecosystem. These findings are supported by the geographical characteristics of Wukirsari Village, where most

agricultural activities rely primarily on rainwater and groundwater rather than primary irrigation canals. As a result, the risk of direct discharge of untreated batik effluents into irrigation networks is minimal, and the likelihood of pollutants entering crop systems through surface water pathways is relatively low.

Nevertheless, while the absence of overt environmental complaints and preliminary research findings are encouraging, it is important to recognize that latent or long-term contamination may still occur if current waste management practices are not gradually improved. Periodic environmental monitoring and upgrading of treatment capacity are therefore recommended to ensure that the sustainability of batik production does not come at the expense of soil health, water quality, or agricultural productivity in the future.

3.3. Green Chemistry Approach for Sustainable Economic and Environmental Balance

To ensure that traditional batik industries like Kampung Batik Giriloyo remain both economically viable and environmentally responsible, the integration of green chemistry principles (**Fig. 3**) into production and waste management practices is essential. In particular, the recycling and reuse of batik wax can significantly reduce raw material costs and minimize environmental impact. This approach aligns with several key principles of green chemistry, including:

- Principle 1: Prevention: Emphasizes waste reduction at the source rather than treatment after formation.
- Principle 5: Safer Solvents and Auxiliaries: Promotes the safe and efficient use or reuse of auxiliary substances such as wax.
- Principle 6: Design for Energy Efficiency: Encourages the use of processes that reduce energy consumption, which is relevant in wax melting and purification.

Figure 3. 12 Principles of Green Chemistry (de Marco et al., 2019). Licensed by Saudi Pharmaceutical Journal

Efforts to recycle wax have been implemented at a basic level in Giriloyo. However, increasing efficiency from under 10% to higher rates requires improvements in wax purification techniques. Globally, several low-cost and effective wax recovery methods have been developed, such as:

- Sedimentation and Filtration Systems: Used in traditional textile industries, where used wax is melted, filtered through fine mesh or activated carbon, and remolded (Lin et al., 2020; Cunha et al., 2025).
- Solvent-Based Purification: A method applied in small-scale candle and crayon industries in Brazil and Malaysia, where safe solvents (e.g., ethanol or coconut oil) are used to remove dye and char residues before reuse (Klotz et al., 2024).
- Micro-filtration and Clay Adsorption: Techniques studied in the Philippines to purify wax using bentonite or kaolin clays, which absorb residual pigments and surfactants from used wax (Missau et al., 2018; Bueno et al., 2021).

These methods are not only cost-efficient and replicable in rural artisan contexts, but they also reduce the need to purchase new wax, which can account for a significant portion of production expenses in hand-drawn batik. The application of green chemistry in Giriloyo could therefore go beyond environmental protection and also hold the potential to enhance the artisans' economic resilience, particularly in the post-pandemic recovery period. With targeted training, collaboration with research institutions, and minor investment in simple purification tools, Giriloyo could become a model for eco-innovative traditional industries rooted in local wisdom yet advancing toward sustainable development.

IV. CONCLUSION

4.1. Conclusion

The implementation of a community-based participatory research program in Kampung Batik Giriloyo has revealed a compelling narrative of resilience, cultural preservation, and growing environmental awareness within a traditional hand-drawn batik industry. Through field observations and interviews, this study found that the community has successfully established localized waste management systems, specifically for wax (*malam*) and synthetic dye effluents, accompanied by clear standard operating procedures (SOPs). These efforts are commendable and demonstrate a strong commitment to sustainability, despite the limited technological infrastructure available.

The recovery and reuse of batik wax, although already practiced, remain relatively inefficient, with less than 10% of used wax being successfully recycled. Similarly, the dye waste treatment process, using alum coagulation and phytoremediation with water hyacinths, has managed to minimize immediate environmental complaints and prevent visible contamination, particularly given the village's geographical reliance on rain-fed and groundwater-based irrigation systems. However, the long-term environmental impact and potential risks of chemical accumulation in surrounding soil and water bodies necessitate continuous improvement and standardized monitoring.

To align batik production with green chemistry principles, especially Principles 1 (Prevention), 5 (Safer Solvents and Auxiliaries), and 6 (Design for Energy Efficiency), the integration of more effective and affordable wax purification technologies, as practiced in other regions globally, offers a pathway for both environmental and economic optimization. These approaches could significantly reduce material costs, increase production efficiency, and reinforce the village's standing as a model for environmentally sustainable cultural heritage industries.

4.2. Recommendations

Based on the findings and analysis, the following concrete recommendations are proposed:

1. For Local Government and Regional Environmental Authorities:
   - Develop support programs for green technology transfer by facilitating partnerships between academic institutions, environmental NGOs, and batik communities.
   - Provide infrastructure subsidies or grants for small-scale waste purification tools (e.g., wax filtration units, dye-neutralizing filters) tailored for artisan-level industries.
   - Establish periodic environmental assessments of batik villages to monitor groundwater, soil, and crop safety, particularly in areas near agricultural land.
2. For Stakeholders and Policy Makers in Cultural and Economic Development:
   - Integrate sustainable batik practices into local tourism branding to increase market value and global appeal.
   - Encourage inter-village cooperation for shared waste treatment facilities, reducing individual burden and enhancing efficiency at scale.
   - Incorporate environmental management modules into batik training and certification programs to instill green chemistry awareness in future artisans.
3. For Community Leaders and Batik Industry Managers in Giriloyo:
   - Invest in the improvement of wax recycling methods, such as adopting multi-stage filtration or low-cost adsorptive purification using natural clays.
   - Document and standardize all waste handling procedures for training and potential replication by other batik communities.
   - Explore collaborations with content creators, researchers, and eco-branding experts to expand the market for eco-batik while raising awareness about environmental practices.

By taking these strategic steps, the Kampung Batik Giriloyo community can strengthen its role as both a guardian of cultural tradition and a pioneer of environmentally responsible craft-based industries, ensuring economic vitality and ecological balance for generations to come.

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REFERENCES

Agus Dwi Cahya, Muinah Fadhilah, Sahilah, & Karyaningsih. (2021). Transformasi Manageria Transformasi Manageria. *Journal Of Islamic Education Management*, *2*(1), 57–72. https://doi.org/10.47476/manageria.v4i1.3907

Ajizah, S., Hidayat, N., & Suhartini, S. (2021). Modelling Green Production Process in the Natural Dyes Batik Industry Using Cleaner Production Options. *Jurnal Riset Teknologi Pencegahan Pencemaran Industri*, *12*(1), 39–54.

Anggarani Pribudi, A. P. (2020). Community-based Approach to Sustain Batik Tourism Village Area in the Special Region of Yogyakarta (The Case of Giriloyo Village). *Journal of Sosial Science*, *1*(4), 113–122. https://doi.org/10.46799/jsss.v1i4.47

Aragaw, T. A., & Bogale, F. M. (2023). Role of coagulation/flocculation as a pretreatment option to reduce colloidal/bio-colloidal fouling in tertiary filtration of textile wastewater: A review and future outlooks. *Frontiers in Environmental Science*, *11*(April).

https://doi.org/10.3389/fenvs.2023.1142227

Bueno, S., Durán, E., Gámiz, B., & Hermosín, M. C. (2021). Formulating low cost modified bentonite with natural binders to remove pesticides in a pilot water filter system. *Journal of Environmental Chemical Engineering*, *9*(1). https://doi.org/10.1016/j.jece.2020.104623

Cunha, S., Santos, L., & Aguiar, J. (2025). Recovery paraffin wax waste as phase change material for application in cement mortars for exterior coatings of buildings. *Journal of Energy Storage*, *129*(June). https://doi.org/10.1016/j.est.2025.117343

de Marco, B. A., Rechelo, B. S., Tótoli, E. G., Kogawa, A. C., & Salgado, H. R. N. (2019). Evolution of green chemistry and its multidimensional impacts: A review. *Saudi Pharmaceutical Journal*, *27*(1), 1–8. https://doi.org/10.1016/j.jsps.2018.07.011

Goswami, D., Mukherjee, J., Mondal, C., & Bhunia, B. (2024). Bioremediation of azo dye: A review on strategies, toxicity assessment, mechanisms, bottlenecks and prospects. *Science of the Total Environment*, *954*(September). https://doi.org/10.1016/j.scitotenv.2024.176426

Hidayati, Y., Siswanto, D., Rumhayati, B., & Retnaningdyah, C. (2024). Characterization of Batik Waste Containing Synthetic Textile Dyes and The Artisan Awareness Regarding The Hazardous Batik Waste. *Biosaintifika: Journal of Biology & Biology Education*, *16*(2), 213–223. https://doi.org/10.15294/biosaintifika.v16i2.2325

Islam, M. R., & Mostafa, M. G. (2020). Characterization of textile dyeing effluent and its treatment using polyaluminum chloride. *Applied Water Science*, *10*(5), 1–10. https://doi.org/10.1007/s13201-020-01204-4

Islam, M., Rakha, A., Nawaj, J., & Mondal, H. (2025). A critical review on textile dye-containing wastewater : Ecotoxicity , health risks , and remediation strategies for environmental safety. *Cleaner Chemical Engineering*, *11*(January).

Karlina, A., Nurochman, I., Risanto, W., Seliah, & Selasi, D. (2024). Eksplorasi Proses Pembuatan Batik Tulis di Plered : Tehnik, Tradisi, dan Inovasi. *Neraca : Jurnal Ekonomi, Manajemen, Dan Akuntansi*, *2*(6), 622–626. http://jurnal.kolibi.org/index.php/neraca

Klotz, M., Oberschelp, C., Salah, C., Subal, L., & Hellweg, S. (2024). The role of chemical and solvent-based recycling within a sustainable circular economy for plastics. *Science of the Total Environment*, *906*(October 2023). https://doi.org/10.1016/j.scitotenv.2023.167586

Lellis, B., Fávaro-Polonio, C. Z., Pamphile, J. A., & Polonio, J. C. (2019). Effects of textile dyes on health and the environment and bioremediation potential of living organisms. *Biotechnology Research and Innovation*, *3*(2), 275–290. https://doi.org/10.1016/j.biori.2019.09.001

Lin, Y. Y., Chen, W. H., & Liu, H. C. (2020). Aging and emulsification analyses of hydrothermal liquefaction bio-oil derived from sewage sludge and swine leather residue. *Journal of Cleaner Production*, *266*. https://doi.org/10.1016/j.jclepro.2020.122050

Missau, J., Rocha, J. de G. da, Dotto, G. L., Bertuol, D. A., Ceron, L. P., & Tanabe, E. H. (2018). Purification of crude wax using a filter medium modified with a nanofiber coating. *Chemical Engineering Research and Design*, *136*(July), 734–743. https://doi.org/10.1016/j.cherd.2018.06.031

Phang, F. A., Roslan, A. N., Zakaria, Z. A., Zaini, M. A. A., Pusppanathan, J., & Talib, C. A. (2022). Environmental Awareness in Batik Making Process. *Sustainability (Switzerland)*, *14*(10), 1–14. https://doi.org/10.3390/su14106094

Safitri, R. A., & Rahmayanti, M. (2020). Characterization and Application of Chitosan as a Natural

Coagulant in Reducing Remazol Red Dyestuff Concentration and COD Value of Batik Liquid Waste. *Jurnal Kimia Sains Dan Aplikasi*, *23*(9), 333–337. https://doi.org/10.14710/jksa.23.9.333-337

Shakir, E., Zahraw, Z., & Al-Obaidy, A. H. M. J. (2017). Environmental and health risks associated with reuse of wastewater for irrigation. *Egyptian Journal of Petroleum*, *26*(1), 95–102. https://doi.org/10.1016/j.ejpe.2016.01.003

Utama, P. B., & Fitriyani, S. (2022). Kajian Kerusakan Lingkungan Pada Perairan Sungai Bedog Akibat Pembuangan Limbah Batik Di Kabupaten Bantul. *Hexagon Jurnal Teknik Dan Sains*, *3*(1), 17–21. https://doi.org/10.36761/hexagon.v3i1.1341

Utami, Y. S., & Cahyana, N. H. (2021). Promotional Innovation of Giriloyo Batik Through Digital Storytelling. *RSF Conference Series: Business, Management and Social Sciences*, *1*(4), 104–108. https://doi.org/10.31098/bmss.v1i4.313

Utomo, H. S., & Susanta, S. (2020). The Effect of Digital Marketing Capability Against Marketing Performance with Innovation as mediation (Study on Batik SMEs during the Covid-19 Pandemic). *LPPM UPN "Veteran" Yogyakarta Conference Series*, *1*(1), 166–173. https://doi.org/10.31098/pss.v1i1.193