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Blue Water Footprint and Grey Water Footprint Assessment of Block-Printed Batik-Making Process Coloured by Indigo (*Indigofera* sp.), Tingi (*Ceriops* sp.) and Mahogany (*Swietenia* sp.) Dyes

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Abstract: The Indonesian batik, which is usually produced by small and medium enterprises (SMEs) often consumes a lot of water and causing environmental pollution. Therefore, a study to map the water use for batik production is required. This study examines the Blue Water Footprint (BWF) and Grey Water Footprint (GWF) of block-printed batik making-process coloured by Indigo (*Indigofera* sp.), Mahogany (*Swietenia* sp.) and Tingi (*Ceriops* sp.) dyes produced by a batik SME in Jarum village of Klaten Regency, Indonesia. The average BWF of block-printed batik making-process coloured by natural dyes was lower than the GWF and Indigo consumes more water in dyeing, followed by Tingi and Mahogany. The dyeing process consumes less water for BWF (2.96 L/pc), while the biggest portion of BWF was contributed from the wax removal process (152.81 L/pc). Implementation of cleaner production by managing the grey water, such as the implementation of communal Wastewater Treatment Plant, adopting water conservation strategies and educating the craftsmen are necessary to achieve batik and water resource sustainability.

Key words: Batik, cleaner production, natural dyes, sustainability, water footprint.

Introduction

The Indonesian batik has been more popular since its recognition by UNESCO in 2009. Although it supports the Indonesian economy, batik small and medium enterprises (SMEs) is causing water pollution (Budiyanto et al., 2018; Mukimin et al., 2018), which in combination with consumptive water use, will result in water scarcity (Pereira et al., 2002). Considering that every textile processor should understand the quantity of water used in the processing (Rather et al., 2019), a study on water required for batik production is required. In textile manufacturing, a study on water use by water footprint approach has been reported (Hossain & Khan, 2020). While the textile industries are represented by large-scaled companies that regularly monitor their water use, in batik SMEs the use of materials, including water, are not accustomed to being monitored and the water use varies with the usage by the craftsmen (Handayani et al., 2019).

According to Nursanti et al. (2018), the water footprint of a block-printed batik was 6.41 L/pc, while the water footprint of a hand-drawn batik cloth coloured by natural dyes is in the range of 3919 L/pc–8159 L/pc (Handayani et al., 2019). Hence, the variation on water footprint might exist as it relates to the direct

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water use and the direct water use for batik production is influenced by some factors, i.e. materials used, production scale, technology and the application by the batik craftsmen (Handayani et al., 2021).

The previous study was focussed on hand-drawn batik fabrics, in general, involving a mixture of natural dye extracts for dyeing with a variety of motifs instead of a specific natural dye (Handayani et al., 2019). However, colour formation is influenced by the natural dyes extract, soaking frequency and the mordants used to fix the colour (Handayani et al., 2020). The dyeing properties of natural dye extracts, such as colour strength and colour fastness, are essential in natural dyeing (Hosen et al., 2021). Usually, the batik dyeing by natural dyes involves repeated dyeing–drying process (Handayani et al., 2020) in order to obtain the expected colour. Extract of stronger colour will require once or twice dyeing–drying process, while softer colour requires a more repeated process, which in turn affects the volume of natural dye extracts used. As the natural dyes are usually extracted by water and are used in their liquid form, the water consumption will increase as the dyeing–drying process takes place. Therefore, in natural dyeing, direct water use which represents the Blue Water Footprint (BWF) and characteristics of the dyes or the wastewater containing the dye—which represents the Grey Water Footprint (GWF)—could be different among the sources of natural dyes. Those differences will affect the water use in total and eventually, the water footprint. This study examines the Blue Water Footprint (BWF) and Grey Water Footprint (GWF) of the block-printed batik-making process of a certain motif, which is coloured using Indigo, Tingi and Mahogany dyes, by a batik SME in Jarum village of Klaten regency, Central Java, Indonesia. The scientific name of Tingi wood is indicated by Rini et al. (2011) and Patil et al. (2019) as *Ceriops tagal*. However, Sheue et al. (2010) reported that the genus Ceriops consists of three species, i.e. *C. tagal* (Perr.) C.B. Rob., *C. zippeliana* Blume and *C. decandra* (Griff.) Ding Hou. Since this study did not intend to conduct taxonomic identification, in order to avoid taxonomic error, the scientific name of Tingi will be mentioned as *Ceriops* sp.

Materials and Methods

This study was conducted in Jarum Village of Klaten Regency, Central Java, Indonesia in a batik SME which produces block-printed batik by natural dyeing. The natural dye batik is usually made through several steps (Handayani et al., 2018) and the pattern was created using a block-print tool. The dyeing was conducted by soaking the fabric into the natural dye extract and dried under the sun. These dyeing-drying processes were repeated until the expected colour is obtained, followed by colour fixation by specific mordants. Finally, the fabric will be boiled, followed by washing and final drying.

Materials Used for Block-Printed Batik Production

The raw materials used for this study are white sanforised cotton fabric in size of 2.0 m × 1.15 m, wax and natural dye extracts (Figure 1). The fabric was soaked in the detergent solution for about thirty minutes, followed by washing and natural drying which was conducted prior to dyeing. The liquid extracts consist of Indigo (*Indigofera* sp.), Mahogany (*Swietenia* sp.) and Tingi (*Ceriops* sp.). The Tingi and Mahogany extracts were prepared by boiling a proportion of barks of corresponding species in five proportions of water, respectively, until two portions of water evaporated. The extracts which consist of three portions of water were usually kept overnight prior to dyeing.

The Indigo stock extract was prepared from fermented Indigo leaves in the form of a paste. A kilogram of Indigo paste, a kilogram of coconut sugar,

(a) (b) (c)

Figure 1: Materials and equipment used in block-printed batik production, i.e. a block-print tool (a), wax (b) and a sample of the natural dye extracts (c) of – left to right – Indigo (*Indigofera* sp.), Mahogany (*Swietenia* sp.) and Tingi (*Ceriops* sp.).

hydrosulphite and lime were dissolved in 32 L of water. The lime was added until the mixture forms a yellowish green colour and was kept overnight until it produced bubbles. For dyeing, 3.20 L of stock solution will be taken and diluted by 3.20 L of water, while for another piece of fabric, a 1.60 L of stock solution is added regularly.

Blue Water Footprint Assessment of Batik Coloured by Natural Dye

BWF represents the water consumed during the process, whether it be incorporated into the product, or evaporated during the process (Hoekstra et al., 2011). Therefore, the BWF during the dyeing process was estimated by measuring the weight of the cotton cloth before (dry phase) and after the cloth is soaked into natural dye extracts (wet phase), repeatedly during dyeing, washing and wax removal processes. The difference in the weight of the cloth is based on the water absorbed by the cloth using the following equation (Handayani et al., 2020):

$$v = \left(\frac{w_1 - w_0}{\rho}\right) \times f_s \quad (1)$$

The notation v represents the water absorbed (ml), while w_0 and w_1 represent the weight (g) of the cloth before and after soaking, respectively. The density of natural dye extracts (g/ml) is represented by ρ and the soaking frequency of the cloth is represented by f_s. The lost return flow and the water evaporates during wax removal were calculated by measuring the water tank volume (Handayani et al., 2018).

Grey Water Footprint Assessment of Batik Coloured by Natural Dye

The GWF indicates the water required to assimilate the pollutants (Hoekstra et al., 2011). As some batik craft industry discharge the wastewater into the soil, the GWF calculation using point source pollution (Hoekstra et al., 2011) cannot be conducted. Therefore, in this study, the GWF is calculated as the water required to dilute the COD until it reaches the acceptable limit set by the Indonesian Government. The samples were taken from washing and wax removal processes at different times and the average was calculated.

The characteristic of wastewater was analysed based on four parameters, i.e. pH, TSS, BOD_5 and COD. The pH was recorded using the HANNA HI 9811-5 kit, TSS was determined using a gravimetric method on a Whatman filter paper of 0.45 µm diameter pore. BOD_5 measurement was conducted using azide modified-iodometry, while the COD was determined using the open reflux titrimetric method. All analyses were conducted based on the method given by Kruis (1995). The COD concentration and quality standard for textile wastewater regulated by the Indonesian government (The Government of Indonesia, 2014) to calculate the GWF has been done according to the following equation:

$$df = \frac{[\text{COD}]\,\text{sample}}{[\text{COD}]\,\text{limit}} \quad (2)$$

By dividing the concentration of COD to the acceptable limit (COD limit), the dilution factor (df) can be obtained. The water required to dilute an ml of wastewater was calculated by reducing df by 1. Finally, the dilution water (dw) in ml is calculated based on the following equation:

$$dw = (df - 1) \times \text{wastewater volume} \quad (3)$$

Colour Intensity Analysis

Colour intensity analysis was conducted to explain the colour produced by all natural dyes after they were applied to the fabrics. Three materials were analysed to determine the colour intensity, i.e. (1) raw materials of the dyes, (2) extract of natural dyes and (3) the batik fabrics which have been coloured by each natural dye by three replications for each coloured batik. A Minolta CR-200 Chromameter was used to measure the colour intensity components in L, a and b values. The total colour difference in $L^*a^*b^*$ colour model was calculated based on the following equation (Magdić et al., 2009):

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \quad (4)$$

It is possible that measurement error happened and influenced the result and the data interpretation. In order to avoid this problem, measurements of colour intensity analysis of each sample was conducted based on five positions of the sample, i.e. upper left, upper right, lower left, lower right and centre positions and the average were performed.

Results and Discussion

The Blue Water Footprint of Block-Printed Batik-Making Process

The BWF of batik-making process for batik fabrics coloured by three natural dyes were similar (Table 1). It is indicated that the dyeing process only consumed 2.96 L/pc of water and water was most consumed during

Indigo colouration, followed by Tingi and Mahogany. More water was used during Indigo colouration for washing, resulting from a higher BWF.

The largest portion of water was used for the wax removal process, i.e., 152.81 L on average (Table 1). The craftsmen usually perform this stage for 68 fabrics, such as Indigo colouration. However, he could use this process for less number of fabrics, i.e. 28 fabrics on Tingi and Mahogany colouration. Therefore, we did not divide the corresponding volume by the number of batik fabrics produced.

Characteristics of Natural Dye Extracts and Batik Wastewater

Table 2 indicates that majority of the parameters that exceeded the acceptable limit regulation imposed by the Indonesian government, except for BOD_5. A high level of COD indicates the high level of organic compounds in the wastewater. In comparison, the wastewater that comes from wax removal has a higher concentration of TSS and COD than the washing process.

The pH of batik wastewater from the wax removal process exceeds the pH limit set by the Indonesian

Table 1: The Blue Water Footprint of block-printed batik coloured by natural dyes

Batik-making process which involved the use of water	*Unit*	*Natural Dyes*			*Average*
		Indigo (Indigofera sp.)	*Tingi (Ceriops sp.)*	*Mahogany (Swietenia sp.)*	
a. Fabric preparation	L/pc				
Starch removal		0.23	0.24	0.19	
Washing		0.24	0.24	0.18	0.44
Total		0.47	0.48	0.37	
b. Dyeing	L/pc				
Volume of extract		0.30	2.57	1.29	
Fixation by mordants		0.24	0.24	0.19	
Washing		3.64	0.24	0.19	2.96
Total		4.18	3.05	1.66	
c. Wax removal	L/pc				
Water in 1st boiling tank		71.39	71.39	71.39	
Water in 2nd boiling tank		52.82	52.82	52.82	
Water evaporated (1st boiling tank)		15.84	15.84	15.84	
Water evaporated (2nd boiling tank)		7.39	7.39	7.39	
Washing		3.19	6.46	6.46	152.81
Total		150.63	153.90	153.90	
d. Drying	L/pc	0.24	0.24	0.19	0.22
BWF of block-printed batik-making process	L/pc	155.52	157.67	156.12	156.44

Table 2: Characteristics of natural dye extract and batik wastewater of block-printed batik

Parameters	*Unit*	*Natural dye extract*			*Batik wastewater*		*Acceptable limit (Indonesian Government, 2014)*
		Indigo	*Tingi*	*Mahogany*	*Wax removal*	*Washing*	
pH	–	9.25	6.50	6.20	9.60	7.57	6.00 – 9.00
TSS	mg/L	284.21	315.67	918.67	3,512.00	317.00	50.00
BOD_5	mg/L	41.25	16.67	45.83	17.50	18.33	60.00
COD	mg/L	2,360	3,610	4,475	12,704.00	604.67	150.00

Government Regulation no 5/2014. The alkaline property of batik wastewater has also been reported by Mukimin et al. (2018) and Birgani et al. (2016), and might correspond to the use of chemicals on the wax removal, i.e. soda ash (Handayani et al., 2018). However, this study indicates a low BOD_5 concentration of the wastewater, although Felaza and Priadi (2016) found that BOD_5 of batik wastewater is in the range of 18.10–81.74 mg/L. Furthermore, Mukimin et al. (2018) reported a high level of BOD_5 at 552 mg/L that corresponds to the presence of starch and dissolved wax in the wastewater. Starch and soda ash are commonly used by batik workers to remove the wax.

Table 2 shows that TSS and COD of batik wastewater are in high concentrations. TSS were usually dominated by alum sulphate, or sodium silicate and undissolved wax (Mukimin et al., 2018). High levels of COD to 870 mg/L, 13,600 mg/L and 1,320.96 mg/L were also reported by Mukimin et al. (2018), Birgani et al. (2016) and Felaza & Priadi (2016), respectively. As previously explained, the calculation of GWF involves the COD concentration of the sample. Therefore, a high level of COD will result on a higher GWF which means a higher volume of water to dilute the pollutants.

Grey Water Footprint of Block-Printed Batik by Natural Dyeing

The GWF of the batik-making process is 17,426.82 L/day (Table 3), which was lower than Tingi and Mahogany. Since the fabrics boiled for Indigo were 68 pcsand 28 pcs for Tingi and Mahogany, GWF will be lower with the higher number of the fabrics boiled. However, bringing the water back to ecosystem in its clean state is important; otherwise, the water use will be inefficient (Hoekstra et al. (2011)).

The higher GWF compared to BWF is similar to Handayani et al. (2019), Hossain & Khan (2020) and Wang et al. (2016). The BWF of textile processing in China reached 1.09 Gm^3/year, while the GWF was 62 Gm^3/year (Wang et al., 2013). In Bangladesh, the BWF of knit and woven products in 2016 were 102 and 77.5 million m^3, while the GWF were 898 and 750 million m^3, respectively (Hossain & Khan, 2020). The sustainability of batik production by SMEs is questionable as the craftsmen still used a lot of water, particularly to dilute the pollutants. A shift to cleaner production is recommended by addressing issues of additional investments, lack of technological know-how, awareness (Hossain et al., 2018), as well as reusing and recycling grey water (Rather et al., 2019). Furthermore, increasing the knowledge of craftsmen on water resources will be of relevance.

Colour Characteristics of Block-Printed Batik by Natural Dyeing

Basically, a piece of natural dye batik consists of some colours as they are used to form specific motifs. Indigo has been used as a natural dye (Elliott, 2004; Patil et al., 2019), as well as Tingi (Patil et al., 2019) and Mahogany bark (Yazaki, 2015). The result of colour intensity analysis is presented in Table 4.

Generally, Indigo is used at the least as it forms a strong blue or dark blue colour (Figure 2a). Therefore, soaking of the cloth into the extract is enough for colouring the fabric. However, a brick red shade of Tingi (Figure 2c) requires ten times of soaking-drying repetition, whereas the brownish hue of Mahogany (Figure 2b) was formed by eight times of the soaking-drying process.

Table 4 shows that the lowest ΔE was found for Indigo, while Mahogany and Tingi only show a small difference. The application of Indigo will first form a greenish blue colour which will turn to blue due to oxidation. This was different from Tingi and Mahogany which are derived from woods. Although the extracts were concentrated and their colours were visually dark, Tingi and Mahogany should be applied repetitively to form concentrated colour. Nevertheless, it is the mordants that play an important role in forming the final colour of the cloth. The blue colour of Indigo was

Table 3: Grey Water Footprint of block-printed batik-making process coloured by natural dyes

Batik-making process which involved the use of water	*Unit*	*Natural Dyes*			*Average*
		Indigo	*Tingi*	*Mahogany*	
COD dilution for wastewater from wax removal process	L/day	17,369.53	17,369.53	17,369.53	17,369.53
COD dilution for wastewater from washing process	L/day	57.29	57.29	57.29	57.29
GWF of block-printed batik-making process	L/day	17,426.82	17,426.82	17,426.82	17,426.82
GWF of block-printed batik-making process	L/pc	256.28	622.39	622.39	500.35

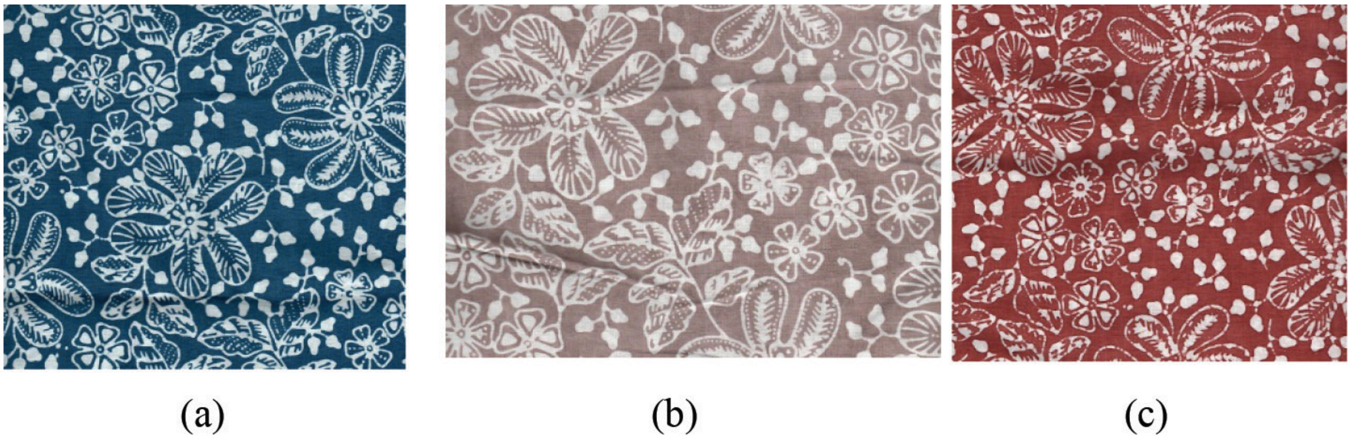

Figure 2: Colour formed by the application of Indigo (*Indigofera* sp.) mordanted by lime (a), Mahogany (*Swietenia* sp.) mordanted by copperas (b) and Tingi (*Ceriops* sp.) mordanted by alum (c).

Table 4: Colour characteristics of natural dyes before and after applied on the cloth

Natural Dyes	L^*	a^*	b^*	ΔE
Mahogany (extract)	26.14	0.91	0.43	
Mahogany (batik)	63.25	4.17	4.79	
Mahogany (Δ)	37.11	3.26	4.36	37.50
Tingi (extract)	25.18	1.48	1.20	
Tingi (batik)	60.61	12.88	12.20	
Tingi (Δ)	35.44	11.40	11.00	38.82
Indigo (extract)	29.57	1.36	-2.00	
Indigo (batik)	50.19	0.15	-9.50	
Indigo (Δ)	20.63	-0.85	-7.50	21.96

fixed by adding lime and vinegar, whereas alum was used to form a red hue when Tingi extract is used and the brownish shade of Mahogany was formed by the addition of copperas.

The result shows that the L^* value of batik coloured by Indigo was lower than Tingi and Mahogany, thus indicating lower lightness of batik coloured by Indigo. Among the three dyes, Tingi shows the highest a^* and b^* values. The high value of a^* indicates the bright reddish tones and the negative b^* value of Indigo indicates blue colour as reported by Magdić et al. (2009) and Geelani et al. (2016).

Conclusions

The average Blue Water Footprint of block-printed batik making process coloured by natural dyes of Indigo, Tingi and Mahogany is 156.44 L/pc, while the Grey Water Footprint is 500.35 L/pc for a batik of 2.00 × 1.15 m in size. The water consumption of the dyeing process is 2.96 L/pc on average, with the highest portion goes to the wax removal process (152.81 L/pc). Although direct water use is commonly used to calculate the water use for batik production, the water footprint approach reveals that incorporation of Grey Water Footprint will result in higher water use for batik production. A shift to cleaner production focussing on water conservation is required by managing grey water, promoting wastewater treatment technology and increasing awareness of batik craftsmen, in order to achieve batik and water sustainability.

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