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The study of environmental impact from fabric dyeing process in Lahanam area, Songkhone district, Lao PDR

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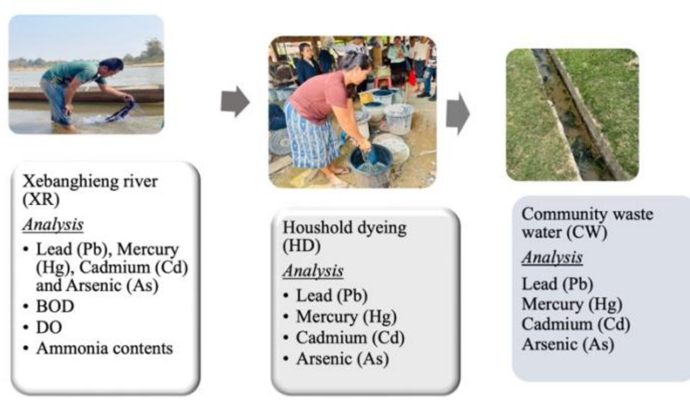
Abstract



The aim of this research was to examine water contamination resulting from the fabric dyeing process in the Lahanam area, located in Songkhone district, Lao PDR. Lahanam is a famous village known for its fabric dyeing and weaving activities, utilizing both natural and chemical dyes which result in the discharge of colors into local water resources. Water samples were collected from three different sources: household dyeing water (HD), community wastewater (CW) and the nearby river, Xebanghieng (XR). Qualitative and quantitative analyses were performed on the water samples. Atomic Absorption Spectroscopy (AAS) was employed to measure the presence of heavy metals such as lead (Pb), arsenic (As), cadmium (Cd) and mercury (Hg). Additionally, tests were conducted to determine the biological oxygen demand (BOD), dissolved oxygen (DO), ammonia contents and pH in the water of Xebanghieng. The results revealed that HD samples contained significantly higher amounts of all four heavy metals (lead 0.217 mg L^{-1}, cadmium 0.105 mg L^{-1}, arsenic 0.029 mg L^{-1} and mercury 0.0014 mg L^{-1}), with lead, cadmium and arsenic exceeding standard limits. These data indicate potential environmental impact of chemical dyeing in the village in the future. Therefore, it is recommended to replace the current dyeing process with more sustainable alternatives, such as natural dyes.

Keyword: Environmental impact; Lahanam area; Water contamination; Dyeing

1. Introduction

Lahanam Village is located in Songkhone District, Savannakhet province, Lao PDR. It is situated along the riverbank and is an area rich in natural resources, surrounded by several important water sources. These include the Xebanghieng which flows into the village from Vietnam, and into the Mekong River at Tha Pasum, opposite the Kammarat district, Ubon Ratchathani province, Thailand. The map of the village showed in Fig. 1. The villagers of Lahanam primarily depend on agriculture for their livelihoods, including rice cultivation, silk weaving, and fabric dyeing, a tradition passed down through generations. The village is renowned for its traditional fabric dyeing methods. This village is renowned for its traditional dyeing techniques, utilizing both chemical and natural methods. However, the dyeing process leads to the environmental contamination after washing, with some chemicals disposed into soils, wastewater and the river. The environmental concern of heavy metals and chemical dyes removal was studied.

The synthetic blue colors can be divided into organic and inorganic compounds. Organic compounds of blue colors consist of sulphonic or carboxyl group incorporated into the natural dye molecules, which do not occur naturally. Inorganic compounds of blue colors consist of various metals, their salts, oxides and hydroxides. Unfortunately, these dyes introduce harmful chemicals into the environment [1, 2]. The toxicity of heavy metals, even at low concentration, poses ecological risks associated with such contaminants. However, the chemical dyeing process has raised environmental concerns due to the potential contamination of water sources with heavy metals which lead to environmental pollution. Some heavy metals are present in synthetic dye to form colors. Arsenic can lead to cardiovascular diseases and is also a known carcinogen. Cadmium can cause Itai-itai disease as well as damage lung and kidneys. Lead exposure is associated with mental retardation and learning disability, while mercury exposure can lead to Minamata disease, nerve cells toxicity, and vision loss [3]. The quality of water resource was also monitored in terms of the amount of oxygen causing trouble aquatic animals. The levels of dissolved oxygen (DO), biochemical oxygen demand (BOD) and ammonia were monitored. The impact of water contamination from the fabric dyeing process, especially from the disposal of chemical dyes, was studied. Proper waste management and eco-friendly dyeing practices are essential to mitigate these negative impacts and protect both the health of the people and the environment. Materials with high surface area and porosity, along with diverse ligands and metal ions were investigated for their capability to eliminate heavy metals and chemical dyes from solutions [4]. Copper ferrite nano particles were studied in the treatment of indigo carmine dye, a chemical dye in wastewater [5].

This study aim was to examine water contamination resulting from the fabric dyeing process, focusing on heavy metals such as arsenic, cadmium, lead and mercury for the environmental impact. To assess the environmental consequences of these contamination, water samples were collected from three different sources: Xebanghieng River (XR) (see Fig. 3a), household dyeing (HD) (see Fig. 3b), and community wastewater (CW) (see Fig. 3c). The levels of heavy metals, including arsenic, cadmium, lead, and mercury, were closely monitored due to their potential risks to humans, animals, and the local ecosystem.

2. Materials and Methods

Instruments

The heavy metals of lead, cadmium, arsenic and mercury were analyzed in Graphite Furnace Atomic Absorption Spectrophotometer (GF-AAS) of Agilent model 240Z AA. Hydride generation of Agilent model VGA-77.

Chemicals

The standard solutions of lead, cadmium, arsenic and mercury at 1000 ppm were obtained from Agilent. Water samples were collected in three different sources in Lahanam area, Songkhone district, Lao PDR. Household dyeing water (HD), community wastewater

(CW) and the nearby river, Xebanghieng (XR) were collected.

Sample preparation

For each 100 mL water sample (HD, CW and XR), 5 mL of concentrated nitric acid was added, followed by gentle heating (without boiling) until the samples reduced to about 5 – 10 mL. After cooling to room temperature, an additional 5 mL of concentrated nitric acid was added, and the samples were heated (without boiling) once more before cooling to room temperature again. The samples were then filtrated and adjusted to a final volume of 100 mL in a volumetric flask.

The preparation of the standard solution

The intermediate standard

A 100 mg L^{-1} intermediate standard solution of lead (Pb) was prepared by pipetting 1000 µL of the stock solution. This intermediate standard solution was then diluted in a 10 mL volumetric flask using 1% nitric acid. Similarly, a 100 mg L^{-1} intermediate standard solution of cadmium (Cd) was prepared by pipetting 1000 µL of the cadmium stock solution and diluting it in a 10 mL volumetric flask with 1% nitric acid. For arsenic (As), a 5 mg L^{-1} intermediate standard solution was made by pipetting 50 µL from the arsenic stock solution into a 10 mL of volumetric flask and adjusting the volume with 1.5% hydrochloric acid. Lastly, a 1 mg L^{-1} intermediate standard solution of mercury (Hg) was prepared by pipetting 10 µL from the mercury stock solution into a 10 mL of volumetric flask and filling it up with 1% of nitric acid.

The working standard solution

The concentration of the working standard solutions of lead, cadmium, arsenic and mercury were prepared by pipetting from the intermediate solutions following the table 1.

Table 1 The concentration of the working standard solutions

	Concentration (mg L^{-1})			
	Lead	Cadmium	Arsenic	Mercury
1	0.2	0.2	0.5	10
2	0.4	0.4	1	20
3	0.6	0.6	2	30
4	0.8	0.8	3	40
5	1.0	1.0	4	50

Note: The standard solutions of lead, cadmium and mercury were adjusted the volume with 1% nitric acid except the standard solution of arsenic that was adjusted the volume with 1.5% of hydrochloric acid.

Fig. 1 The map of Lahanam village

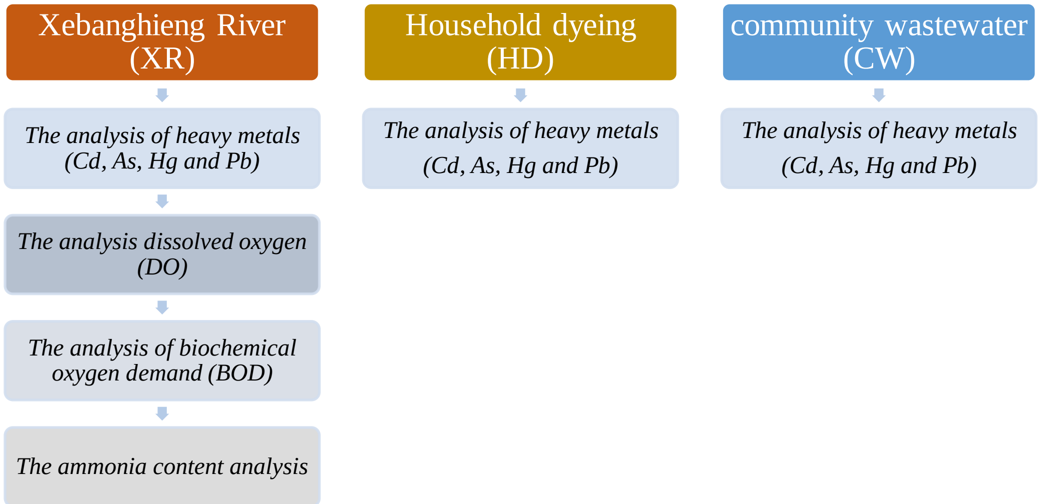


Fig. 2 The experimental flowchart

Fig. 3a Xebanghieng River (XR)

Fig. 3b Household dyeing (HD)

Fig. 3c community wastewater (CW)

The analysis of heavy metal

The analysis method followed the procedure outlined by Rodger *et al* [6]. Quantification of heavy metals, lead, cadmium, arsenic and mercury was measured at their specific wavelengths. The analysis was performed using a Graphite Furnace Atomic Absorption Spectrophotometer (GF-AAS) of the Agilent model 240Z AA. Calibration lines were plotted under optimum condition. Samples from Xebanghieng river (XR), household dyeing water (HD) and community wastewater (CW) were determined in triplicated using the Graphite Furnace Atomic Absorption Spectrophotometer.

The analysis dissolved oxygen (DO)

The method was followed Rodger *et al.* [6], Xebanghieng river water (XR) was collected and stored in 300 mL of BOD bottle. To this, 1 mL of manganese sulfate solution and 1 mL alkali – iodide – azide solution were added. The bottle was set aside until precipitates formed and the water became clear, filling about half of the bottle. Afterward, 1 mL of concentrated sulfuric acid was added, and the mixture was shaken. The sample was then titrated with 0.025 N sodium thiosulphate until the yellow color disappear. Starch solution was added as an indicator, and the titration continued until the blue color disappear.

The analysis of biochemical oxygen demand (BOD)

The method was followed Rodger *et al* [6]. In a 1000 mL cylinder, 50 mL of Xebanghieng water (XR), 200 mL of deionized water, and 2 mL of microorganisms were combined. Additional deionized water was added to reach a total volume of 1000 mL. The mixture was gently stirred with a plastic rod around 20 times to prevent the formation of air bubbles. The samples were then divided into 3 BOD bottles, and care was taken to remove any bubbles before sealing the bottles with caps. Two of the bottles were placed in an incubator at a temperature of 20 ± 1 °C for 5 days for the final dissolved oxygen (DO) analysis, while the third bottle was kept at room temperature for the initial DO analysis. The DO content of the samples was determined by measuring the difference between the initial and the final DO concentrations.

The ammonia content analysis

The method was followed Roger *et al.* [6]. A 25 mL sample from Xebanghieng river (XR) was pH-adjusted to neutral, filtered and transferred into a 125 mL Erlenmeyer flask. Subsequently, 1 mL of phenol solution, 1 mL of sodium nitroprusside, and 2.5 mL of an oxidizing agent were added to the sample and thoroughly mixed. The mixture was then allowed to stand at room temperature (between 22 and 27 °C) in low light condition for at least 1 hour until color development occurred. The absorbance of the sample was measured at a wavelength of 640 nm.

3. Results and Discussion

From the results in table 2, the HD sample contained significantly the highest amount of all four heavy metals (lead 0.217 mg L^{-1}, cadmium 0.105 mg L^{-1}, arsenic 0.029 mg L^{-1} and mercury 0.0014 mg L^{-1}) and also the amounts of lead, cadmium and arsenic exceeded the standard limits, posing a potential risk [7 – 9]. Furthermore, the river water was found to be contaminated with excessive levels of lead and cadmium which exceeded the standard limits. These results indicate severe contamination of lead, cadmium and arsenic in the water of Lahanam village, particularly in the drainage water after dying process. The findings suggest health risks for the villagers. A study on the levels of certain heavy metals in Lake Nassar, Egypt, revealed concentrations of cadmium (0.025 – 0.06 mg L^{-1}) and lead (0.01 – 0.04 mg L^{-1}), both of which were found to be below the standard limit. [10]

According to Table 3, the water quality in Xebanghieng river (XR) is in a critical state. The dissolved oxygen levels (DO) were recorded at 2.94 mg L^{-1}, which ideally should be higher than 6.0 mg L^{-1} based on the standard groundwater data in Thailand and should ideally fall between 5 – 7 mg L^{-1} according to the World Health Organization (WHO) [7 – 9]. This low oxygen level is insufficient to support aquatic life in the river, despite the presence of numerous aquatic species that require adequate oxygen. The diminished dissolved oxygen content also impacts the biochemical oxygen demand (BOD) value, which ideally should be below 1.5 mg L^{-1} (the standard of ground water in Thailand) or should range between 2 – 6 mg L^{-1} according to WHO guidelines. However, the river water exhibited a BOD value of 8.4 mg L^{-1}, indicating that some oxygen has been consumed by organisms in the river.

Various types of dyes, including direct dyes, acid-base, reactive, vat, disperse, sulfur and azoic dyes are commonly used in the dyeing process. The chemical structures of these organic dyes, which contain chromophores such as azo group and nitro groups, pose a risk of water pollution due to their toxic properties when introduced into water systems. During the dyeing process, unfixed dyes are released into wastewater, significantly increasing the biological oxygen demand (BOD) value, as observed in studies by Sela et al. [11].

The ammonia levels exceeded the permissible limit of 0.84 mg L^{-1}, which ideally should be below 0.5 mg L^{-1} (Standard ground water of Thailand) or 0.2 mg L^{-1} (according to WHO guildlines) to ensure safety. This excessive ammonia content has disrupted the homeostasis of fish, leading to their mortality [12].

Indigo carmine, a synthetic blue dye extensively used, consists of benzene rings and sulfonates in its structure. It is highly toxic and carcinogenic to both humans and aquatic animals, as highlighted in research by El-Kammah et al. [13]. This dye is primarily employed to achieve navy blue hues, notably in products like jeans or indigo fabric. Villagers may choose the synthetic dye due to its convenience, allowing for effortless production of navy-blue fabric compared to the complexities associated with natural dyeing using indigo leaves. Subsequent research will focus on the removal of heavy metals and chemical dyes before releasing them into water resources.

Table 2 Results of the heavy metal analysis

	Heavy metals (mg L^{-1})			
	Lead (Pb)	Cadmium (Cd)	Arsenic (As)	Mercury (Hg)
Xebanghieng river (XR)	0.024 ± 0.05	0.019 ± 0.002	0.001 ± 0.001	< 0.0005 ± 0.0001
household dyeing water (HD)	0.217 ± 0.003	0.105 ± 0.001	0.029 ± 0.002	0.0014 ± 0.0001
community wastewater (CW)	0.002 ± 0.002	0.001 ± 0.001	0.001 ± 0.001	<0.0005 ± 0.0002
Standard groundwater of Thailand	**≤ 0.05**	**≤ 0.005**	**≤ 0.01**	**≤ 0.002**
World Health Organization (WHO)	**≤ 0.01**	**≤ 0.003**	**≤ 0.01**	**≤ 0.001**

Table 3 Results of water quality analysis in Xebanghieng river

	DO (mg L^{-1})	BOD (mg L^{-1})	Ammonia content (mg L^{-1})
Xebanghieng river (XR)	2.94 ± 0.01	8.40 ± 0.20	0.84 ± 0.02
Standard groundwater of Thailand	**≥ 6.0**	**≤ 1.5**	**≤ 0.5**
World Health Organization (WHO)	**5 – 7**	**2 – 6**	**0.2**

4. Conclusion

The concentrations of lead, cadmium, arsenic and mercury should not exceed 0.05 mg L^{-1}, 0.005 mg L^{-1}, 0.01 mg L^{-1} and 0.002 mg L^{-1}, respectively [7 – 9]. Unfortunately, lead (0.217 mg L^{-1}), cadmium (0.105 mg L^{-1}) and arsenic (0.029 mg L^{-1}) exceeded the specified limits in household dyeing (HD). Additionally, lead (0.024 mg L^{-1}) and cadmium (0.019 mg L^{-1}) in Xebanghieng river (XR) surpassed the permissible limits, posing risks to the local population and community. The dissolved oxygen (DO) concentration in Xebanghieng river was notably low, falling below 6.0 mg L^{-1}. The biochemical oxygen demand (BOD) level in the river also exceeded 1.5 mg L^{-1} [7 – 9].

5. Suggestions

The results revealed that the village environment was polluted with various heavy metals, adversely affecting the main river and leading to a crisis in oxygen levels within the ecosystem. The residents of the village are suffering due to these contaminations, highlighting the urgent need for action to address the situation. Effective measures, such as employing absorption materials like banana leaves [14], agriculture by – products [15], chitosan [11] must be taken to remove heavy metals before disposal. Encouraging the use of natural dyes in the dyeing process is essential to decrease the reliance on chemical colors, which often contain harmful substances.

6. Acknowledgement

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