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Chemical Factors in Clothes Wastewater Affect the Development of *Aedes aegypti* Mosquitoes

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ABSTRACT

Dengue hemorrhagic fever is caused in part by *Aedes aegypti*. *Ae. aegypti's* primary breeding habitat is a non-groundwater reservoir. Chemical variables including pH, salinity, Dissolved Oxygen (DO), and Total Dissolved Solids (TDS) all have an impact on the growth of *Ae. aegypti* larvae. The purpose of this study is to examine the effect of water chemistry parameters on egg hatchability as well as the number of *Ae. aegypti* larvae and pupae in clothes washing wastewater. The experimental design in this study was a Completely Randomized Design (CRD) with three treatment media (washing clothes wastewater from dengue patients' houses, water municipal waterworks, and abate) three repetitions. The parameters measured are egg hatchability, number of larvae, number of pupae, dissolved oxygen (DO), pH, salinity, and total dissolved solids. The data were analyzed using one-way ANOVA and the Honestly Significant Difference (BNJ) test at a 5% confidence level. The results showed that wastewater from washing clothing had a 26.00% affect on the hatchability of *Ae. aegypti*, 22.67% of the larvae, and 10.67% of the pupae. The chemical content in clothes washing wastewater for DO is 7.60 mg/L, TDS is 136.00 ppm, pH is 7.80, and salinity is 0.10%. The chemical content of DO and TDS in clothes washing wastewater differs greatly from water municipal waterworks and abate water, while pH and salinity do not differ significantly. This study concludes that wastewater from washing clothes has the potential to serve as a breeding ground for the *Ae. aegypti* mosquito, which transmits the dengue virus.

INTRODUCTION

Dengue hemorrhagic fever (DHF) is a major vector-borne disease caused by the dengue virus and transmitted through the bite of infected Aedes aegypti mosquitoes. The World Health Organization (2023) has classified DHF as a rapidly spreading global health problem, with over 390 million infections per year worldwide, leading to severe complications and mortality, particularly in tropical and subtropical regions (Wang et al., 2023). In Indonesia, the Ministry of Health (2024) reported 16,000 cases of DHF across 213 districts/cities, resulting in 124 deaths. In early March 2024, the Palembang Health Service recorded 371 cases, including 5 deaths, with the Sukarami subdistrict reporting 66 cases from January to March 2024, making it the highest-risk area for DHF transmission in the region (Dinkes, 2024). This district has remained among the top five DHF hotspots for the past three years, recording 41 cases in 2023, 61 in 2022, and 29 in 2021 (Dinkes, 2024).

Aedes aegypti is a highly adaptive mosquito species that thrives in urban and semi-urban environments. The species prefers stagnant water for oviposition but can tolerate a wide range of water conditions, including polluted and chemically altered environments (Newman et al., 2024). Although traditionally associated with clean water, multiple studies indicate that Aedes aegypti can successfully reproduce in various water sources, including wastewater and chemically contaminated habitats (Lin et al., 2022; Day, 2016).

The breeding success of Aedes aegypti is determined by multiple physical, chemical, and biological factors (Huzortey et al., 2023). Temperature, turbidity, and pH are critical physical parameters, while salinity, total dissolved solids (TDS), and dissolved oxygen (DO) influence larval development (Mamai et al., 2021; Herawati et al., 2022). The ability of Aedes aegypti to withstand fluctuations in pH and salinity levels allows the species to exploit anthropogenic water sources, including laundry wastewater, which is often rich in chemical additives such as surfactants, phosphates, and organic compounds (Yitbarek et al., 2023; Medeiros-Sousa et al., 2020).

Several studies suggest that chemical pollution, particularly from detergents and wastewater effluents, enhances the survival and reproductive success of Aedes aegypti (Avramov et al., 2024; Prameswarie et al., 2023). Surfactants and organic residues in laundry wastewater can create nutrient-rich environments, increasing egg hatchability and larval survival rates (Day, 2016).

Research by Mamai et al. (2021) found that mosquito larvae exposed to wastewater with high phosphate levels exhibited accelerated growth rates, suggesting that phosphates act as larval nutrients. Similarly, Putri et al. (2023) demonstrated that an increase in TDS concentration enhances larval metabolic activity, leading to higher pupation rates. Furthermore, Avramov et al. (2024) reported that fluctuations in pH levels can alter the availability of dissolved oxygen (DO), which in turn affects larval respiration and survival rates.

The pH range of 6–10 in laundry wastewater makes it a potential breeding site for Aedes aegypti, as it falls within the mosquito's preferred oviposition conditions (Suwartawan et al., 2021). However, despite growing evidence on the ecological impacts of wastewater, few studies have explicitly examined the effects of laundry wastewater on mosquito populations, particularly in endemic DHF areas (Qudsi, 2021; Prameswarie et al., 2023).

Although previous studies have explored mosquito breeding habitats and their environmental determinants, limited research has investigated the specific impact of laundry wastewater on Aedes aegypti reproduction (Wang et al., 2023; Medeiros-Sousa et al., 2020). Understanding how detergents and chemical additives in wastewater influence mosquito development is essential for vector control strategies, particularly in urban areas where domestic wastewater is abundant (Mamai et al., 2021).

This study focuses on examining the effects of chemical parameters in laundry wastewater on Aedes aegypti egg hatchability, larval survival, and pupal formation in DHF-endemic areas of Palembang City (Dinkes, 2024). The results are expected to enhance current knowledge on mosquito breeding ecology and contribute to effective mosquito control measures through wastewater management and public health interventions (Yitbarek et al., 2023).

METHOD

Study Design

This study employs a quantitative experimental research approach using a Completely Randomized Design (CRD) with a minimum of three replications. CRD is a widely used statistical approach in ecological and entomological research, allowing for the minimization of bias and the identification of significant differences among treatment groups. The research was conducted at the Microbiology and Parasitology Laboratory, Faculty of Medicine, Muhammadiyah University, Palembang, from September to December 2024.

Sample Collection and Preparation

This study utilized three primary water sources to evaluate their effects on Aedes aegypti development: clothes washing wastewater (first rinse), municipal waterworks water, and abate-treated water. Clothes washing wastewater was collected from households of dengue patients in Sukajaya Village, as identified through data from the Sukarami Community Health Center. Municipal waterworks water was obtained from the water storage area of the Faculty of Medicine, Muhammadiyah University, Palembang. Meanwhile, abate-treated water was prepared by adding 0.0012 mg of abate (temephos) per 1 mL of municipal waterworks water, following the standard vector control guidelines (Ebnudesita et al., 2021; World Health Organization, 2023). To maintain consistency and ensure reliability in the experimental setup, all collected water samples were stored in sterile containers and kept at ambient temperature (27–30°C) before use. Additionally, the chemical composition of the water samples, including pH, dissolved oxygen (DO), salinity, and total dissolved solids (TDS), was analyzed prior to the experiment to confirm uniformity across the experimental conditions.

Mosquito Egg Source and Experimental Setup

The Aedes aegypti eggs used in this study were obtained from the Baturaja Public Health Laboratory and were subjected to an acclimatization process under laboratory conditions, where they were maintained at a temperature of 25–30°C, relative humidity of 70–80%, and a 12:12 light-dark cycle. The eggs were placed on ovisstrips, which serve as oviposition substrates, and were then submerged in the three different treatment water sources to assess the effects of water chemistry parameters on egg hatchability, larval survival, and pupal development.

Each experimental unit consisted of a plastic tray (10 × 25 × 8 cm) containing 1 liter of the respective test water. In each tray, 100 Aedes aegypti eggs were immersed for 48 hours, following standardized experimental protocols (Avramov et al., 2024). To enhance the reproducibility and statistical reliability of the findings, this procedure was repeated three times for each treatment group. To ensure experimental control, several conditions were kept constant across all treatments, including temperature (27–30°C) and relative humidity (70–80%), which were regulated using a climate-controlled chamber. Additionally, light conditions (12-hour light/dark cycle) were standardized to mimic natural environmental settings (World Health Organization, 2023). Throughout the incubation period, all experimental trays were kept undisturbed to prevent external contamination or mechanical disturbances that could affect the outcomes.

Measurement of Water Chemistry Parameters

To determine the impact of chemical factors on Aedes aegypti development, key water quality parameters were measured every 24 hours using calibrated instruments to ensure precision and reliability. Dissolved Oxygen (DO) was measured using a HACH HQ40D DO meter, while pH levels were assessed using a Hanna HI98107 pH meter (Mamai et al., 2021). Salinity levels were determined with a YSI Pro30 salinity meter (Day, 2016), and Total Dissolved Solids (TDS) were measured using a Hanna HI98301 TDS meter (Putri et al., 2023). All equipment was calibrated before use, and triplicate measurements were conducted for each parameter to ensure accuracy and minimize experimental bias (Medeiros-Sousa et al., 2020).

Assessment of Mosquito Development Stages

The impact of water chemistry on mosquito development was evaluated by recording three key biological parameters every 24 hours for a total duration of 5 days. The first parameter, egg hatchability rate (%), was calculated as the proportion of eggs that successfully hatched into larvae (Prameswarie et al., 2023). The larval survival rate (%) was determined as the percentage of larvae that remained alive during the observation period (Newman et al., 2024), while the pupal formation rate (%) was assessed by measuring the proportion of larvae that successfully transitioned into pupae. Observations of these mosquito development stages were conducted using a stereomicroscope (Leica EZ4), which facilitated accurate identification and counting of eggs, larvae, and pupae.

Sample Size Determination and Statistical Analysis

The sample size for each treatment group was determined using power analysis ($\alpha = 0.05$, power = 80%), ensuring that the number of eggs per treatment was statistically sufficient to detect significant differences between experimental groups. The collected data were subjected to statistical analysis using appropriate parametric methods. A one-way ANOVA was employed to determine significant differences between treatment groups, while Tukey's Honestly Significant Difference (HSD) test was performed at a 95% confidence level ($p < 0.05$) to assess pairwise comparisons (Avramov et al., 2024). All statistical analyses were conducted using IBM SPSS Statistics 27 and GraphPad Prism 9, ensuring a rigorous and standardized data interpretation process.

RESULTS OF STUDY

Water Chemical Content (Dissolved Oxygen, Ph, Salinity, And Total Dissolved Solids)

The chemicals in each water, washing clothes wastewater, water municipal waterworks, and abate water were measured. The chemicals included dissolved oxygen, pH, salinity, and total dissolved solids. The chemical concentration of each treatment water varies, which affects the growth of *Ae. aegypti* eggs. Table 1 summarizes the results of the chemical content analysis of dissolved oxygen water.

The results of the analysis of table 1 of the chemical content of dissolved oxygen water show that the amount of dissolved oxygen (dissolved oxygen) in washing clothes wastewater shows significantly different results on days 2 and 4, indicating that dissolved oxygen has an influence on hatchability, number of larvae, and pupae, whereas days 0, 1, 3, and 5 showed no significant difference. Aside from that, the clothes washing wastewater treatment and water municipal waterworks treatment had the same result of 7.60 mg/L, while the abate water treatment had the lowest result of 7.47 mg/L. Table 2 shows the pH levels in each treatment of clothes washing wastewater, water municipal waterworks, and abate water.

The results of Table 2 show that the amount of pH water chemical content varies between treatments. The water chemistry (pH) data revealed that clothes washing wastewater produced no significant differences, implying that pH had no effect on hatchability, larval quantity, or pupae. Aside from that, the clothes washing wastewater treatment and the water municipal waterworks treatment yielded the same 7.80, however the abate water treatment yielded 6.00.

Table 3 shows the salinity concentration of each treatment of clothes washing wastewater, water municipal waterworks, and abate water. The analysis of the chemical content of water (salinity) in table 3 produced results that were same for each treatment, indicating that salinity had no effect on hatchability, larval number, or pupae. The salinity level in clothes washing wastewater was the same as in water municipal waterworks and abate water treatment, at 0.10%.

Table 1
Water Chemical Amount (Dissolved Oxygen)

Treatment	Water Chemical Amount (Dissolved Oxygen) (mg/L)					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Washing Clothes Wastewater	7,60	7,60	7,60a	7,60	7,60a	7,60
Water Municipal Waterworks	7,60	7,60	7,60a	7,60	7,60a	7,60
Air Abate	7,53	7,50	7.47b	7,50	7,47b	7,53
F Count	1,32 ns	3,00 ns	16,00 *	3,00 ns	16,00 *	1,32 ns
P Value	$3,36 \times 10^{-1}$	$1,25 \times 10^{-1}$	$3,94 \times 10^{-3}$	$1,25 \times 10^{-1}$	$3,94 \times 10^{-3}$	$3,36 \times 10^{-1}$
BNJ 5%	-	-	0,01	-	0,16	-

Note that ns = not substantially different, * = significantly different, ^{a} = highest number, and ^{b} = lowest number. At the 5% BNJ test rate, numbers separated by the same letter in the same column do not differ appreciably. During data processing, we applied square root transformation (SQRT) to the original data.

Table 2
Water Chemical Amount (pH)

Treatment	Water Chemical Amount (pH)					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Washing Clothes Wastewater	6,70a	7,80a	7,70a	7,70a	7,70a	7,70a
Water Municipal Waterworks	7,10a	7,80a	7,10a	7,63a	7,70a	7,70a
Abate water	6,00a	6,00a	6,00a	6,00a	6,00a	6,00a
F Count	0,46 ns	0,12 ns	0,10 ns	0,12 ns	2,15 ns	0,13 ns
P Value	$9,55 \times 10^{-1}$	$8,88 \times 10^{-1}$	$9,05 \times 10^{-1}$	$8,87 \times 10^{-1}$	$1,98 \times 10^{-1}$	$8,78 \times 10^{-1}$
BNJ 5%	-	-	-	-	-	-

Note that ns = not substantially different, * = significantly different, ^{a} = highest number, and ^{b} = lowest number. At the 5% BNJ test rate, numbers separated by the same letter in the same column do not differ appreciably. During data processing, we applied square root transformation (SQRT) to the original data

The data presented in Table 4 illustrate the Total Dissolved Solids (TDS) measurements for three water treatments—washing clothes wastewater, water municipal waterworks, and abate-treated water—over a six-day observation period. The TDS levels, expressed in ppm, show significant differences across treatments, with statistical significance indicated by the F count and p-values for each day. Washing clothes wastewater consistently exhibits the highest TDS values, remaining stable at 136.00 ppm from Day 0 to Day 5. This treatment is marked with "a," indicating a statistically significant difference compared to the other treatments at the 5% BNJ test rate. The stable TDS levels in this treatment reflect the persistent presence of dissolved solids, which may include minerals, salts, and organic matter, contributing to its distinct chemical composition.

In contrast, water municipal waterworks and abate-treated water display similar patterns of TDS measurements. Both treatments start with a TDS value of 49.67 ppm on Day 0, which drops to 42.00 ppm on Day 1 before stabilizing back at 49.67 ppm from Day 2 to Day 5. These treatments are marked with "b," indicating no significant difference between them throughout the observation period. The temporary reduction in TDS on Day 1 could be attributed to a dilution effect or a chemical reaction that temporarily affects the dissolved solids content. Despite this slight fluctuation, the consistently lower TDS levels in these treatments suggest they are less enriched with dissolved substances compared to washing clothes wastewater.

The F count values for all observation days range from 10.487 to 19.376, with corresponding p-values ranging from 2.34×10^{-11} to 3.71×10^{-12}, confirming a statistically significant difference in TDS levels among the treatments. This indicates that the chemical composition of washing clothes wastewater is significantly different from that of municipal waterworks and abate-treated water. In summary, washing clothes wastewater is characterized by a higher and stable TDS concentration, while municipal waterworks and abate-treated water maintain consistently lower TDS levels. These differences highlight the unique chemical properties of each water source, which may have implications for environmental and biological processes related to water quality.

Table 3
Water Chemical Amount (Salinity)

Treatment	Water Chemical Amount (Salinity) (%)					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Washing Clothes Wastewater	0,10	0,10	0,10	0,10	0,10	0,10
Water Municipal Waterworks	0,10	0,10	0,10	0,10	0,10	0,10
Abate Water	0,10	0,10	0,10	0,10	0,10	0,10
F Count	1,00ns	1,00ns	1,00ns	1,00ns	1,00ns	1.00ns
P Value	4,22 × 10^{-1}	4,22 × 10^{-1}	4,22 × 10^{-1}	4,22 × 10^{-1}	4,22 × 10^{-1}	4.22 × 10^{-1}
BNJ 5%	-	-	-	-	-	-

Note that ns = not substantially different, * = significantly different, ^{a} = highest number, and ^{b} = lowest number. At the 5% BNJ test rate, numbers separated by the same letter in the same column do not differ appreciably. During data processing, we applied square root transformation (SQRT) to the original data.

Table 4
Water Chemical Amount (Total Dissolved Solids)

Treatment	Water Chemical Amount (Total Dissolved Solids) (ppm)					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Washing Clothes Wastewater	136.00a	126,00a	136,00a	136,00a	136,00a	136.00a
Water Municipal Waterworks	49,67b	42,00b	49,67b	49,67b	49,67b	49.67b
Abate Water	49,67b	42,00b	49,67b	49,67b	49,67b	49.67b
F Count	19,376*	10.487*	19,376*	19,376*	19,376*	19.376*
P Value	3,71 × 10^{-12}	2.34 × 10^{-11}	3,71 × 10^{-12}	3,71 × 10^{-12}	3,71 × 10^{-12}	3.71 × 10^{-12}
BNJ 5%	0,08	0.11	0,08	0,08	0,08	0.08

Note that ns = not substantially different, * = significantly different, ^{a} = highest number, and ^{b} = lowest number. At the 5% BNJ test rate, numbers separated by the same letter in the same column do not differ appreciably. During data processing, we applied square root transformation (SQRT) to the original data.

Table 5
Amount of Egg Hatchability of *Aedes aegypti*

Treatment	Percentage of Egg Hatchability of *Aedes aegypti* (%)					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Washing Clothes Wastewater	0,00	0,00	15,00a	22,67a	26,00a	26,00a
Water Municipal Waterworks	0,00	0,00	0,00b	4,33b	4,33b	4,33b
Abate Water	0,00	0,00	0,00b	0,33b	2,67b	2,00b
F Count	0,00ns	0,00ns	22,72*	26,11*	26,43*	19,72*
P Value	0,00	0,00	11,59 × 10^{-3}	1,09 × 10^{-3}	1,06× 10^{-3}	2,3 × 10^{-3}
BNJ 5%	-	-	11,31	11,15	15,66	12,36

Note that ns = not substantially different, * = significantly different, ^{a} = highest number, and ^{b} = lowest number. At the 5% BNJ test rate, numbers separated by the same letter in the same column do not differ appreciably. During data processing, we applied arcsin transformation to the original data.

Egg Hatchability, Number of Eggs Becoming Larvae, and Amount of Larvae Developing Into Pupae

Ae. aegypti eggs were placed in a tub of water with three treatments: washing clothes wastewater, water municipal waterworks, and abate water. The hatchability, or percentage of the eggs' ability to hatch, was measured. Table 5 shows the results of the percentage study of egg hatchability.

The examination of the hatchability percentage of the eggs showed varied results for each treatment. The percentage of egg hatchability showed significant changes between days 2, 3, 4, and 5, demonstrating that wastewater from clothes washing affected the hatchability of Ae eggs. However, the results from days 0 and 1 were not statistically different. Aside from that, wastewater from washing clothing had the highest percentage of Ae egg hatchability. On the fifth day, *Ae. aegypti* was 26.00%, whereas Water Municipal Waterworks and abate water were 4.33% and 2.00%, respectively. We found no Ae mosquito eggs on day 0 or day 1. This is because the egg phase lasts between two and three days. We also calculate the percentage of larvae that develop after the eggs hatch.

Table 6 shows the percentage of eggs that develop into larvae as a result of variations in how clothes washing wastewater, water municipal waterworks and abate water are treated. The examination of the percentage of larvae showed different results for each treatment. On days 2, 3, 4, and 5, the percentage of larvae discovered in laundry wastewater varied dramatically. This suggests that wastewater from clothes washing had an effect on the amount of *Ae. aegypti* larvae. The results did not differ significantly between days 0 and 1. Aside from that, wastewater from washing clothing contains the highest percentage of *Ae. aegypti* larvae on the third day was 22.67%, whereas in the water Municipal Waterworks treatment, the highest was observed on the fifth day, 5.33%, and in the abate water treatment, the lowest was 0.00% from day 0 to day 3.5. Abate water contains temephos, a larvicide that kills *Ae. aegypti* mosquito larvae. We also calculate the percentage of pupae that develop after the larvae mature.

Table 7 shows the percentage of larvae that develop into pupae as a result of variations in how clothes washing wastewater, water municipal waterworks, and abate water are treated. The pupa percentage analysis revealed that clothes washing wastewater had significantly different results on days 4 and 5, implying that clothes washing wastewater had an effect on the number of *Ae. aegypti* pupae, whereas the results on days 0, 1, 2, and 3 were not significantly different. Aside from that, clothes washing wastewater had the largest percentage on the fifth day, at 10.67%, compared to water municipal waterworks and abate water, which were 0.67% and 0.00%, respectively. From day 0 to day 3, no pupae were detected. The larvae died completely in the abate water treatment, resulting in the formation of no pupae.

DISCUSSION

Water Chemical Content (Dissolved Oxygen, pH, Salinity, and Total Dissolved Solids)

The chemical composition of the three tested water sources—clothes washing wastewater, municipal waterworks water, and abate-treated water—revealed significant variations in dissolved oxygen (DO), pH, salinity, and total dissolved solids (TDS). These chemical parameters directly influenced the hatchability of Aedes aegypti eggs, larval survival, and pupal formation.

Table 6
Amount of Eggs That Develop Into Larvae *Aedes aegypti* (%)

Treatment	Percentage of eggs that develop into larvae *Ae. aegypti* (%)					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Washing Clothes Wastewater	0,00	0,00	15,00a	22,67a	26,00a	26,00a
Water Municipal Waterworks	0,00	0,00	0,00b	4,33b	4,00b	5,33b
Abate Water	0,00	0,00	0,00b	0,33b	2,67b	2,00b
F Count	0,00ns	0,00ns	22,72*	34,48*	77,30 *	51,89 *
P Value	0,00	0,00	$11,59 \times 10^{-3}$	$5,13 \times 10^{-4}$	$5,21 \times 10^{-5}$	$1,63 \times 10^{-4}$
BNJ 5%	-	-	11,31	10,28	6,35	6,91

Note that ns = not substantially different, * = significantly different, ^{a} = highest number, and ^{b} = lowest number. At the 5% BNJ test rate, numbers separated by the same letter in the same column do not differ appreciably. During data processing, we applied arcsin transformation to the original data.

Tabel 7
Amount of larvae to pupae *Aedes aegypti* (%)

Treatment	Percentage of larvae to pupae *Ae. aegypti* (%)					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Washing Clothes Wastewater	0,00	0,00	0,00	0.00	6.67a	10,67a
Water Municipal Waterworks	0.00	0.00	0,00	0.00	0,33b	0,67b
Abate Water	0,00	0.00	0.00	0.00	0,00b	0,00b
F Count	0,00ns	0,00ns	0,00ns	0,00ns	19,29 *	32,58 *
P Value	0,00	0,00	0,00	0,00	$2,44 \times 10^{-3}$	$5,99 \times 10^{-3}$
BNJ 5%	-	-	-	-	7,54	7,36

Note that ns = not substantially different, * = significantly different, ^{a} = highest number, and ^{b} = lowest number. At the 5% BNJ test rate, numbers separated by the same letter in the same column do not differ appreciably. During data processing, we applied arcsin transformation to the original data.

DO plays a crucial role in mosquito larval development, as oxygen availability determines metabolic activity and survival rates. In this study, DO levels in clothes washing wastewater and municipal waterworks water remained stable over five days, while abate-treated water exhibited the lowest DO levels. This aligns with research by Herawati et al. (2022), which found that higher DO concentrations correspond to greater larval abundance. The DO levels in the experimental setup ranged between 5.86 and 8.98 mg/L, falling within the optimal range for Aedes aegypti larval development.

The pH values of all tested water sources remained within a neutral to slightly alkaline range (6–10) and did not significantly affect egg hatchability or larval survival. This finding is consistent with studies by Prameswarie et al. (2023) and Suwartawan et al. (2021), which report that Aedes aegypti can tolerate a wide pH range as long as other environmental conditions, such as DO and nutrient availability, remain favorable.

Similarly, salinity levels remained low across all treatments, with values below 4 g/L, which falls within the suitable range for Aedes aegypti breeding (Hidayah & Rahmawati, 2019). However, studies suggest that when salinity exceeds 6 g/L, larval growth may be inhibited due to osmotic stress (Anggraini & Cahyati, 2017). In this study, salinity fluctuations did not significantly alter mosquito reproduction, indicating that salinity was not a limiting factor.

TDS levels were highest in clothes washing wastewater, significantly differing from municipal waterworks and abate-treated water. Previous research indicates that TDS is composed of minerals, salts, and organic matter, which can serve as nutrients for mosquito larvae (Putri et al., 2023; Medeiros-Sousa et al., 2020). Aedes aegypti larvae typically thrive in environments with an average TDS of 102 ppm, whereas Aedes albopictus larvae can tolerate up to 128.5 ppm (Novianto et al., 2021). This suggests that the higher TDS concentration in clothes washing wastewater may have contributed to enhanced larval survival and pupation rates compared to the other water sources.

Effect of Detergent Chemical Composition on Aedes aegypti Larval Development

The findings indicate that clothes washing wastewater provided a more favorable environment for egg hatchability, larval survival, and pupal formation compared to the other two treatments. This is primarily due to the chemical composition of detergents, which contain surfactants, phosphates, and organic compounds that influence mosquito development.

Surfactants present in detergents reduce surface tension in water, allowing mosquito eggs to remain afloat and hatch more successfully (Mamai et al., 2021). This observation aligns with Qudsi et al. (2021), who found that detergent residues create an ideal oviposition site for Aedes aegypti by mimicking organic-rich environments.

Phosphates, commonly found in detergents, promote microbial growth, which in turn provides a nutritional source for mosquito larvae (Day, 2016). This explains why higher larval survival rates were observed in clothes washing wastewater, as phosphate-enriched water promotes bacterial growth, supplying an indirect food source for developing larvae (Avramov et al., 2024).

The high TDS content in clothes washing wastewater was another contributing factor to increased larval survival and pupation rates. Studies have shown that mosquito larvae can tolerate high dissolved solids concentrations, as these compounds may provide essential minerals and nutrients (Putri et al., 2023). In contrast, abate-treated water exhibited significantly lower larval survival, reinforcing the role of TDS and organic matter in larval sustenance (Medeiros-Sousa et al., 2020).

Egg hatchability, amount of eggs becoming larvae, and amount of larvae developing into pupae

The comparison of egg hatchability, larval survival, and pupal formation across the three treatments revealed that clothes washing wastewater resulted in the highest mosquito reproduction rates. Egg hatchability was significantly higher in clothes washing wastewater, consistent with findings from Pratama et al. (2020), which showed that Aedes aegypti prefers detergent-contaminated water for oviposition. The presence of ammonia, carboxylic acids, and lactic acid in soap formulations may act as chemical attractants, drawing mosquitoes to lay eggs in these environments (Agustin et al., 2017).

Conversely, municipal waterworks water had lower hatchability rates, likely due to chlorine content, which has been shown to oxidize and inhibit mosquito egg development (Suparyati & Himam, 2021). Abate-treated water resulted in no successful egg hatching, consistent with its known larvicidal effects (Ebnudesita et al., 2021).

Larval survival rates followed a similar trend, with clothes washing wastewater supporting the highest survival. This corroborates Prameswarie et al. (2023), who found that municipal waterworks water inhibited mosquito development due to residual chlorine. In contrast, all larvae in abate-treated water died after hatching, likely due to cholinesterase inhibition, which disrupts nerve function in mosquito larvae, leading to paralysis and death (Fenisenda & Rahman, 2016).

Pupal formation was also highest in clothes washing wastewater, reinforcing the hypothesis that detergent residues create an optimal environment for mosquito development (Pratama et al., 2020). The municipal waterworks treatment resulted in lower pupation rates, likely due to chlorine toxicity, while abate treatment completely prevented pupation.

LIMITATIONS OF THE STUDY

While this study provides valuable insights into the relationship between laundry wastewater and mosquito reproduction, some limitations must be acknowledged. First, the study did not quantify the exact detergent concentration in the wastewater samples, making it difficult to determine the threshold level at which chemical exposure influences egg hatchability and larval survival. Future research should incorporate a dose-response analysis to establish the minimum concentration of surfactants, phosphates, and other chemicals required to impact mosquito development (Newman et al., 2024).

Second, this study focused primarily on egg hatchability and larval development, without assessing the impact of wastewater on adult mosquito emergence and longevity. Since adult mosquito survival directly affects vector transmission rates, further investigations should evaluate how exposure to detergent-polluted water influences mosquito fitness, reproductive success, and biting behavior (Huzortey et al., 2023). Lastly, environmental factors such as temperature fluctuations and microbial activity in wastewater were not accounted for, despite their potential influence on larval development. Future studies should incorporate field-based experiments to validate these laboratory findings under natural conditions (Reinhold et al., 2018).

Implications for DHF Vector Control Strategies

The findings of this study have significant implications for dengue vector control programs, particularly in urban areas where wastewater mismanagement is common. Given that clothes washing wastewater provides a suitable breeding ground for Aedes aegypti, efforts to improve wastewater disposal practices should be integrated into public health policies (World Health Organization, 2023). One potential intervention is the treatment of household wastewater before discharge, using natural filtration systems or bioremediation techniques to reduce organic matter and chemical pollutants (Prameswarie et al., 2023). Additionally, community-based awareness campaigns should educate the public on proper wastewater management and the risks of mosquito breeding in stagnant water bodies (Trewin et al., 2017).

Furthermore, this study reinforces the importance of integrating larvicidal treatments (e.g., temephos) in high-risk areas to prevent mosquito proliferation. The effectiveness of abate-treated water in significantly reducing larval survival supports its continued use in vector control programs, although resistance monitoring should be conducted to ensure long-term efficacy (Ebnudesita et al., 2021). Lastly, urban planning strategies should incorporate environmental modifications, such as proper drainage systems to prevent wastewater accumulation, thereby eliminating mosquito breeding sites. Cities experiencing high DHF incidence rates should adopt integrated vector management (IVM) approaches, combining biological, chemical, and environmental control strategies for sustainable mosquito control (Wang et al., 2020).

CONCLUSIONS AND RECOMMENDATION

This study highlights the role of laundry wastewater as a potential breeding ground for Aedes aegypti, emphasizing the need for enhanced wastewater management practices in dengue-endemic regions. The chemical composition of wastewater, particularly TDS, DO, and organic compounds, directly influences mosquito egg hatchability and larval survival, supporting previous findings that chemical pollution exacerbates mosquito breeding success (Lin et al., 2022).

While pH and salinity had minimal effects on mosquito development, the presence of nutrient-rich compounds in detergent-contaminated water provides an ideal habitat for larval growth and survival. These findings underscore the urgent need for targeted interventions, such as household wastewater treatment, larvicidal applications, and community education programs, to mitigate mosquito proliferation in urban settings. Future research should focus on quantifying detergent exposure thresholds, assessing adult mosquito fitness, and evaluating real-world wastewater management strategies for more effective dengue vector control.

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